

Gulf of Maine-Georges Bank Acadian Redfish

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1.0 Background

The most recent stock assessment of Acadian redfish in Subarea 5 was completed and reviewed at the 2nd Groundfish Assessment Review Meeting in August 2005 (Mayo *et al.* 2005, Mayo *et al.* 2007). The assessment was based on several analyses including trends in catch/survey biomass exploitation ratios; a yield and biomass per recruit analysis; an age-structured dynamics model which incorporates information on the age composition of the landings, size and age composition of the population, and trends in relative abundance derived from commercial CPUE and research vessel survey biomass indices (NEFSC 2001a, 2001b).

Based on the most recent assessment, estimates of redfish population biomass have been increasing in recent years. The increase in biomass estimates is produced by corresponding increases in both the NEFSC spring and autumn survey biomass indices which had increased substantially during the mid-1990s and have remained relatively high through 2005. The rapid increase in abundance and biomass was attributed to strong recruitment for some cohorts in the early-1990s. The state of this stock was reviewed at the 2005 Groundfish Assessment Review Meeting by comparing the estimated 2005 spawning biomass with spawning biomass at MSY (estimated previously, NEFSC 2002). Estimates of fishing mortality derived from the age-structured dynamics model in the last assessment have been less than 10% of F_{MSY} since 2000 (<0.004). The 2004 spawning biomass was estimated to be about 175,790 mt (74% of SB_{MSY}) and the 2004 fishing mortality rate estimate was 0.0024 ($F_{MSY} = F_{50\%} = 0.04$). Thus, it was concluded that the stock was deemed not overfished and overfishing is not occurring.

For the 2008 Groundfish Assessment Review Meeting (Model Meeting), we have updated the catch and survey data to 2006 and provide estimates of discards between 1989 and 2006. In the last assessment two versions of the statistical catch at age model (RED and STATCAM) were explored, but the definitive results were ultimately based on the RED model. As such, we have also used both RED and STATCAM to estimate assessment model parameters and we have also made estimates using landings data from 1913-1933 that we found primarily in annual reports of the U.S. Bureau of Fisheries (e.g., Fielder 1928). We also note that, for consistency, we used the same version of STATCAM as that used in the 2005 assessment.

We also used an alternative finite-state continuous-time population dynamics model (FSCTPD) on a limited set of age measurements from surveys and landings between 1969 and 1985 to estimate recruitment, selectivity, survey catchability and annual fishing mortality (see Miller 2008). The statistical framework is the same as that described by Miller and Andersen (2008) for various types of tagging experiments. We compared the results from FSCTPD with corresponding results from the RED and STATCAM models for corroborative purposes.

2.0 The Fishery

Substantial exploitation of Acadian redfish began in the the late 1930s and was highest in the 1940s (Table N1, Figure N1). Landings declined drastically in the early 1950s but continued to range from about 8,000 – 20,000 mt annually until the early 1980s. Landings of redfish declined steeply throughout the 1960s, but stabilized somewhat in the 1970. Finally landings dropped

steeply again in the 1980s and remained below 1,000 mt per year since 1989, and at less than 600 mt per year since 1994.

2.1 Discards

We estimated discards using the d/k ratio method described in Wigley et al. (2006). The discard estimates are generally low (< 400 mt), but are sometimes a substantial proportion of total removals (discards and landings). One particularly high estimate in 1991 is roughly 3 times the corresponding landed biomass but the precision is estimated quite low ($CV = 0.74$).

2.2 CPUE

The redfish fishery in the Gulf of Maine has traditionally taken very low bycatch of other species. For example, over 70% of the redfish landed during 1964-1978 were taken on trips comprising over 85% redfish (Mayo 1980). Estimates of commercial catch per unit effort (CPUE) indices from these trips were considered representative of trends in stock biomass (Table N1). These indices are available from the early 1940s through the late 1980s but have since been discontinued. These indices declined sharply during the 1940s and 1950 which presumably indicate that the biomass was fished down. The CPUE indices increased during the 1960 following recruitment of several strong year classes from the 1950 (Mayo 1980) but afterward showed a steady decline.

2.3 Biological Sampling

As a consequence of the relatively low landings of redfish after the mid 1980s, age measurements from landings halted after 1985 (Tables N2). Authors of previous assessments derived estimates of catch at age between 1969 and 1985 (Figure N2). Estimates of weight and proportion mature at age were also derived for previous assessments (Table N3).

3.0 Research Survey Estimates

We estimated annual numbers and biomass per tow and mean fish weight and length for the NEFSC spring and autumn research vessel bottom trawl surveys (Tables N4 and N5, Figures N3-N6). For both surveys, the estimates of annual numbers and biomass per tow are generally low and have generally higher precision between the late 1970s and middle 1990s than annual estimates from years outside this range. This period roughly corresponds to the last decline in landings. The increase in annual estimates of numbers and biomass per tow since the middle 1990s is accompanied by increased estimates of uncertainty. Note that although there is increased uncertainty in higher estimates of numbers and biomass per tow, the relative uncertainty (CV) is fairly consistent across all years.

In a few of the yearly surveys, there were sampling deficiencies in some strata. For the spring survey in 1975 no trawls were made in stratum 1390 and this stratum is not included in estimation for that year. For the fall survey, only one trawl was made in stratum 1300 in 1963 and in stratum 1400 in 2004 so that stratified sampling variance estimates over sets of strata where these are included is not possible.

3.1 Survey Age Composition

Age samples from the NEFSC autumn bottom trawl survey are available from 1975 through 2006. As illustrated in Figures N7 - N10, abundance estimates at age appear to show infrequent large cohort recruitment pulses followed by periods of small cohort recruitment between 1975 and the early 1990s. Several strong cohorts began to appear in the early 1990s and the biomass in the middle age classes appears to be building at present.

4.0 Assessment Results

For the 2008 Groundfish Assessment Review Models Meeting, we estimated assessment parameters using RED and STATCAM models with the same data as Mayo et al. 2005 except we updated landings and survey data through 2006 (including proportions at age for the fall survey). Mayo *et al.* (2002) and STATCAM (2005) provide full descriptions of RED and STATCAM models, respectively.

We considered base RED and STATCAM models that use the same likelihood weighting factors as Mayo et al. (2005), but found these models to provide trends in annual biomass estimates that were biologically unrealistic when landings between 1913 and 1933 were included (Figure N11, Table N6). Because the weightings gave unreasonable population trends when small annual landings prior to 1934 were included, there may be reason to question that the weightings are appropriate for the shorter time series of landings. Furthermore, the estimates of spawning biomass in 1930s are 2 to 5 times higher using the base RED model than the same model in the last assessment with data only up to 2004. Therefore, we explored different weightings for both RED and STATCAM models to find a model that would both provide biologically plausible trends in biomass and recruitment and reasonable residual patterns for the various data components (Table N6). In addition to the changes in weightings for the RED model, we had to change the minimization phase of the (log) fishing mortality parameters from 2 to 4 and that for (log) survey selectivity parameters from 4 to 8.

The Alternative 1 models for RED and STATCAM give more reasonable trends in spawning biomass and (log) recruitment estimates, but for RED, the biomass estimate in 1934 is less than half the corresponding estimate for the base RED model using the shorter landings time series (Figure N11). FOR STATCAM Alternative 1 the 1934 spawning biomass estimate is similar to the corresponding estimate for the base model and shorter landings time series, but the current (2006) biomass estimate is about 3 times the corresponding estimate with the shorter landings series. Furthermore, the (log) landings residuals are much noisier and show substantial decreasing trend over time for the RED Alternative 1 model whereas the (log) CPUE and fall and spring biomass per tow residuals show a decreasing trend over time for the STATCAM Alternative 1 model (Figure N12).

STATCAM Alternatives 2 and 3 show better trends in spawning biomass estimates than the base models when fitting the longer times series of landings and have similar biomass estimates in the earliest years and the current biomass estimates for these models are similar to the corresponding estimates for the base models using the shorter times series of landings (Figure N11). The trend in spawning biomass when landings start to increase dramatically in the late 1930 to early 1940s for

Alternative 3 appears to be slightly better than Alternative 2 only in that the biomass estimates for Alternative 2 nearly reach zero around 1945. Both of these models do not show any strong patterns in the (log) residuals from the landings, CPUE and survey biomass per tow estimates (Figure N12) and exhibit as good or better fits to the proportions at age in the landings and surveys than the base RED model (Figures N13-N15). Finally, the estimates of spawning biomass for the 1930s using Alternatives 2 and 3 are more in line with the corresponding estimates from Mayo et al (2005).

The results from fitting the FSCTPD model (Miller 2008) allowed comparison of a subset of STATCAM and RED estimates with corresponding estimates from an entirely different model. The fishing mortality estimates between 1969 and 1985 using the FSCTPD model are very similar to corresponding estimates provided by several of the RED and STATCAM models and the trend in (log) recruitment estimates is the same for FSCTPD and many of the RED and STATCAM models (Figure N16). However, the FSCTPD model generally provides greater recruitment estimates for a given year. This pattern should be expected because Age 0 recruitment is estimated in the FSCTPD model whereas Age 1 recruitment is estimated by the RED and STATCAM models, but the difference is much greater than the assumed natural mortality rate (0.05).

Given the results of the considered RED and STATCAM models and comparisons with the FSCTPD model we recommended either STATCAM Alternative 2 or 3 models for the Gulf of Maine- Georges Bank Acadian redfish stock assessment. Further development of the FSCTPD model would be necessary to allow estimation of total biomass and recruitment earlier than 1969 when the landings age measurements began.

Using STATCAM Alternative 2, fishing mortality in 2006 is estimated at 0.0026 and the 2006 spawning biomass estimate is 196,031 mt. Using STATCAM Alternative 3, fishing mortality in 2006 is estimated at 0.0027 and the 2006 spawning biomass estimate is 189,343 mt.

The reviewers at the 2008 Groundfish Assessment Review Models Meeting, were concerned with the problematic estimation of biomass levels prior to the substantial landings starting 1936 using RED and STATCAM. The reviewers suggested implementing a Beverton-Holt stock-recruitment relationship with a steepness as estimated for Pacific Ocean Perch and assume low coefficient of variation (CV, approximately 0.2) of log recruitment residuals in years where age samples is not available and high CV (approximately 0.4) of log recruitment residuals where age samples are available. The reviewers were also interested in relaxing the constant selectivity assumption (i.e., the separability assumption).

In the revised assessment, we have used ASAP (ASAP 2008) as the assessment model because it is also a statistical catch-at-age model and it has options for assuming a Beverton-Holt stock-recruitment relationship. We fit three ASAP models assuming the suggested CVs for log recruitment residuals (0.2 and 0.4, alternative 1) assuming more drastic differences in the CVs for periods with and without age sampling (0.1 without age samples and 0.8 with age samples, alternative 2) and assuming the same CVs as alternative 2 except with a 5 year linear ramp from 0.1 in 1964 to 0.8 in 1969 (alternative 3). In addition, we revised the maturity at age (Figure N17), weight at age (Figure N18) and assumed CVs for survey biomass indices and we included

discards with landings for total catch estimates between 1989 and 2006 with corresponding CVs provided by variance estimates for the annual discards. The CVs for the biomass indices were estimates provided by the sampling design used in the fall and spring bottom trawl surveys when available. In years where design-based CV estimates were not possible, we assumed $CV = 0.3$. Further assumptions in the ASAP models were intended to mimic those used previously in STATCAM and RED models where possible (Table N7). However, we have not attempted to relax the constant selectivity assumption in this assessment because the time span over which age composition data are available from landings (1969-1985) is short relative to the entire time span of landings (1913-2006) and as such there is no ability to estimate different selectivity patterns in the periods prior to and after age observations from landings.

Estimates of spawning biomass in the initial period are better behaved using any of the ASAP alternatives (1, 2, or 3) than either STATCAM alternatives 2 or 3 (Figure N19). However, the 2006 spawning biomass estimates from ASAP alternatives 1 and 2 are slightly lower than those from the STATCAM models whereas ASAP alternative 3 provides a greater 2006 spawning biomass estimate. The spawning biomass estimates in the initial period (1913 to 1934) provided by the ASAP alternatives are all greater than those provided by the STATCAM alternatives. Furthermore, the magnitude of the infrequent large recruitment estimates is generally less using the ASAP models. The residuals of log catch, survey indices and recruitment show little differences from those of the STATCAM models over time (Figure N20). There are some large deviations of predicted total catch in the 1990s for the ASAP models, but this reflects the CVs assumed that are derived from the variance of discards during this period.

The estimated steepness is greater and the unexploited spawning biomass is less under the recruitment variance assumptions of ASAP alternative 1, than the corresponding estimates under alternatives 2 or 3 (Table N8). Estimates of MSY , spawning biomass at MSY and current (2006) spawning biomass are also less under ASAP alternative 1 whereas estimated instantaneous fishing mortality at MSY is slightly greater under ASAP alternative 1. Age-specific fishery and survey selectivity parameter estimates are similar under the alternative ASAP models; the largest disparity occurs in estimates of fall survey selectivity on Age 2 fish (approximately 0.93 for alternative 1 to 0.80 for alternative 3). As expected, the variability in recruitment residuals is generally greater under the alternative ASAP models for years after 1968 when age observations are available and the assumed CV is greater (Figure N21). However, the range in standardized recruitment residuals is least for ASAP alternative 3 where a linear transition from low to high CVs is assumed. There are no apparent differences among the three alternative ASAP models in general fits of the proportions at age in the surveys and landings (Figure N22).

Overall, the diagnostics of the three ASAP alternatives were similar and estimation of initial stock biomass was better behaved than any of the STATCAM alternatives. However, we propose ASAP alternative 3 as the best of the alternative assessment models at this time because the standardized recruitment residuals were best behaved.

5.0 Biological Reference Points

Estimates of recruitment obtained from an age-structured biomass dynamics model reviewed at the 33rd SAW were used to imply the probable recruitment that could be produced by a rebuilt stock

as described in NEFSC (2002). Recruitment estimates derived by the model from the 1952-1999 year classes served as the basis for evaluating trends and patterns in recruitment. The stock and recruitment estimates suggest an increase in the frequency of larger recruitment events (> 50 million fish) at higher biomass levels. Therefore recruitment estimates corresponding to the upper quartile of the SSB range served as the basis for deriving mean and median recruitment estimates. In accordance with the recommendation of the Stock Assessment Review Committee of the 33rd SAW, the estimate of $F_{50\%}$ (0.04) was taken as a proxy for F_{MSY} .

The reference points as defined in NEFSC (2002) are

MSY	8,235mt
SB_{MSY}	236,700 mt
F_{MSY}	$0.04 = F_{50\%} MSP$

It was determined (NEFSC 2002) that the stock could not be rebuilt to B_{MSY} by 2009 even at $F=0.0$. Therefore, the rebuilding scenario invoked a 10 year plus 1 mean generation time (31 years for Acadian redfish) to achieve rebuilding. This results in an $F_{rebuild} = 0.013$.

Using ASAP Alternative 3, fishing mortality in 2006 is estimated at 0.0024 and the F_{MSY} estimate (Table N8) is almost identical to the NEFSC (2002) estimate. The 2006 spawning biomass estimate is 215,720 mt and the SB_{MSY} estimate is somewhat lower (207,580 mt) than the NEFSC (2002) estimate.

For the 2008 Groundfish Assessment Review Biological Reference Point Meeting, we re-evaluate the reference points and the current status of the population relative to those reference points. We use AGEPRO (AGEPRO 2005) to determine median spawning biomass under two alternative scenarios. In the first scenario, we assume recruitment events are related to spawning biomass in the same manner as the ASAP alternative 3 with 0.8 CV for the residuals (Beverton-Holt Spawner-Recruit relationship) and the stock is fished at F_{MSY} with fishery age-specific selectivity as estimated from that model. In the second scenario, we assume recruitment is a random draw from the 94 recruitment estimates provided by ASAP alternative 3 and the stock is fished at $F_{50\%MSP}$ (0.03780) as determined from the revised weight at age and maturity at age and fishery age-specific selectivity as estimated from ASAP alternative 3. For both projection scenarios, we used 100 draws of numbers at age vectors in 2007 from the posterior distribution provided by ASAP alternative 3 and we projected 300 years forward with 100 simulations per numbers at age vector.

The median spawning biomass at MSY as estimated using AGEPRO, using the first scenario with a Beverton-Holt spawner-recruit function is approximately 358,100 mt whereas the median using the 94 estimated recruitments from ASAP is approximately 262,400 mt. Both of these SB_{MSY} estimates are greater than the NEFSC (2002) estimate.

Because the median SB_{MSY} using scenario 1 with the Beverton-Holt spawner-recruit function was so much larger than the estimate provided by ASAP alternative 3 (Table N8) we also did projections with negligible variation in recruitment. However, the estimated SB_{MSY} (approximately 258,300 mt) is still greater than the estimate provided by ASAP alternative 3.

Regardless of the appropriate SB_{MSY} estimate, the 2006 spawning biomass estimate from ASAP alternative 3 is greater than 50% of the SB_{MSY} and would not be considered overfished. Likewise, the 2006 instantaneous fishing mortality is a small fraction of the F_{MSY} (provided by ASAP alternative 3) or the previous $F_{rebuild}$ estimate and, as such, overfishing is not occurring.

7.0 References

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Table N1. Nominal redfish catches (metric tons), actual and standardized catch per unit effort, calculated standardized USA and total effort and estimated discards for the Gulf of Maine-Georges Bank redfish fishery.

Year	Nominal Catch (Metric tons)			USA Catch per Unit		Calculated Standard Effort (days fished)		Estimated		Total	
	USA	Others	Total	Actual	Standard	USA	Total	Discards (mt)	CV	Removals (mt)	
1913	7	*	7	*						7	*
1914	30	*	30	*						30	*
1915	40	*	40	*						40	*
1916	53	*	53	*						53	*
1917	82	*	82	*						82	*
1918	73	*	73	*						73	*
1919	25	*	25	*						25	*
1920	31	*	31	*						31	*
1921	13	*	13	*						13	*
1922	9	*	9	*						9	*
1923	7	*	7	*						7	*
1924	40	*	40	*						40	*
1925	25	*	25	*						25	*
1926	30	*	30	*						30	*
1927	30	*	30	*						30	*
1928	57	*	57	*						57	*
1929	34	*	34	*						34	*
1930	54	*	54	*						54	*
1931	108	*	108	*						108	*
1932	60	*	60	*						60	*
1933	120	*	120	*						120	*
1934	519		519							519	
1935	7549		7549							7549	
1936	23162		23162							23162	
1937	14823		14823							14823	
1938	20640		20640							20640	
1939	25406		25406							25406	
1940	26762		26762							26762	
1941	50796		50796							50796	
1942	55892		55892	6.9	6.9	8100	8100			55892	
1943	48348		48348	6.7	6.7	7216	7216			48348	
1944	50439		50439	5.4	5.4	9341	9341			50439	
1945	37912		37912	4.5	4.5	8425	8425			37912	
1946	42423		42423	4.7	4.7	9026	9026			42423	
1947	40160		40160	4.9	4.9	8196	8196			40160	
1948	43631		43631	5.4	5.4	8080	8080			43631	
1949	30743		30743	3.3	3.3	9316	9316			30743	
1950	34307		34307	4.1	4.1	8368	8368			34307	
1951	30077		30077	4.1	4.1	7336	7336			30077	
1952	21377		21377	3.5	3.4	6287	6287			21377	
1953	16791		16791	3.8	3.6	4664	4664			16791	
1954	12988		12988	3.4	3.1	4190	4190			12988	
1955	13914		13914	4.5	4.0	3479	3479			13914	
1956	14388		14388	4.4	3.8	3786	3786			14388	
1957	18490		18490	4.3	3.6	5136	5136			18490	
1958	16043	4	16047	4.4	3.6	4456	4458			16047	
1959	15521		15521	4.3	3.5	4435	4435			15521	
1960	11373	2	11375	3.8	3.0	3791	3792			11375	
1961	14040	61	14101	4.6	3.5	4011	4029			14101	
1962	12541	1593	14134	5.4	4.0	3135	3534			14134	

1963	8871	1175	10046	4.1	3.0	2957	3349										10046
1964	7812	501	8313	4.3	2.9	2694	2867										8313
1965	6986	1071	8057	7.0	4.4	1588	1831										8057
1966	7204	1365	8569	11.7	6.4	1126	1339										8569
1967	10442	422	10864	12.4	5.6	1865	1940										10864
1968	6578	199	6777	14.7	6.1	1078	1111										6777
1969	12041	414	12455	11.4	4.9	2457	2542										12455
1970	15534	1207	16741	9.0	4.0	3884	4185										16741
1971	16267	3767	20034	7.0	3.2	5083	6261										20034
1972	13157	5938	19095	5.7	2.9	4537	6584										19095
1973	11954	5406	17360	5.3	2.9	4122	5986										17360
1974	8677	1794	10471	5.0	2.6	3337	4027										10471
1975	9075	1497	10572	4.0	2.2	4125	4805										10572
1976	10131	565	10696	4.6	2.3	4405	4650										10696
1977	13012	211	13223	4.9	2.5	5205	5289										13223
1978	13991	92	14083	4.8	2.4	5830	5868										14083
1979	14722	33	14755	3.6	1.9	7748	7766										14755
1980	10085	98	10183	3.2	1.6	6303	6364										10183
1981	7896	19	7915	2.7	1.4	5640	5654										7915
1982	6735	168	6903	2.7	1.5	4490	4602										6903
1983	5215	113	5328	2.1	1.2	4346	4440										5328
1984	4722	71	4793	1.9	1.1	4293	4357										4793
1985	4164	118	4282	1.4	0.9	4627	4758										4282
1986	2790	139	2929	1.0	0.6	4650	4882										2929
1987	1859	35	1894	1.1	0.7	2656	2706										1894
1988	1076	101	1177	0.9	0.5	2152	2354										1177
1989	628	9	637	1.1	0.6	1047	1062	32	*	0.62	*					669	*
1990	588	13	601	**	**			38	*	0.49	*					639	*
1991	525		525	**	**			1514	*	0.74	*					2039	*
1992	849		849	**	**			129	*	0.30	*					978	*
1993	800		800	**	**			246	*	0.53	*					1046	*
1994	440	*	440	**	**			106	*	2.60	*					546	*
1995	440	*	440	**	**			191	*	0.47	*					631	*
1996	322	*	322	**	**			367	*	0.37	*					689	*
1997	251	*	251	**	**			181	*	0.44	*					432	*
1998	320	*	320	**	**			266	*	0.97	*					586	*
1999	353	*	353	**	**			30	*	0.51	*					383	*
2000	319	*	319	**	**			169	*	0.48	*					488	*
2001	360	*	360	**	**			368	*	0.33	*					728	*
2002	368	*	368	**	**			126	*	0.37	*					494	*
2003	361	*	361	**	**			203	*	0.19	*					564	*
2004	398	*	398	**	**			125	*	0.18	*					523	*
2005	564	*	564	**	**			101	*	0.15	*					665	*
2006	499	*	499	**	**			149	*	0.24	*					648	*

* Preliminary

** CPUE and effort not calculated due to sharp reduction in directed redfish trips

Table N2. Number of length and age measurements by year and quarter and annual landings and biological samples for Gulf of Maine-Georges Bank Acadian redfish between 1969-1985.

Year	Number of length measurements				Number of age measurements				Annual Landings (mt)	Number of samples	Landings per sample
	1	2	3	4	1	2	3	4			
1969	200	1000	2000	0	40	178	398	0	12455	14	890
1970	200	900	1100	100	40	180	241	0	16741	18	930
1971	1196	2399	3201	1000	160	359	279	181	20034	34	589
1972	100	3026	1659	300	20	631	350	65	19095	16	1193
1973	1401	3141	1405	299	264	467	204	67	17360	23	755
1974	2407	2518	2217	803	263	335	251	162	10471	34	308
1975	2558	3097	916	300	411	494	198	46	10572	27	392
1976	1200	2747	2523	1624	234	278	252	261	10696	24	446
1977	3398	2148	2322	627	227	239	273	125	13223	31	427
1978	2470	1423	869	731	434	214	201	162	14083	30	469
1979	1132	1693	3569	2581	213	225	310	377	14755	35	422
1980	1308	1964	1385	201	292	418	354	45	10183	21	485
1981	800	1704	703	511	198	375	175	103	7915	21	377
1982	1262	1020	1321	613	246	186	284	131	6903	27	256
1983	1351	1020	1717	1012	295	195	284	220	5328	31	172
1984	1552	1959	624	609	353	448	84	133	4793	26	184
1985	931	1345	1808	1691	223	330	468	443	4282	37	116

Table N3. Weight and proportion mature at age assumed for RED and STATCAM models.

	Weight (kg)	Proportion mature
1	0.01	0.01
2	0.02	0.02
3	0.059	0.05
4	0.099	0.15
5	0.145	0.36
6	0.178	0.64
7	0.201	0.85
8	0.25	0.95
9	0.272	0.98
10	0.31	0.99
11	0.348	1
12	0.391	1
13	0.423	1
14	0.429	1
15	0.463	1
16	0.495	1
17	0.503	1
18	0.508	1
19	0.548	1
20	0.558	1
21	0.565	1
22	0.581	1
23	0.595	1
24	0.583	1
25	0.582	1
26+	0.637	1

Table N4. Estimated catch per tow, average weight and average length of Gulf of Main-Georges Bank Acadian redfish for all inshore and offshore strata (24, 26-30, 36-40) in the spring NEFSC bottom trawl survey.

Year	Numbers/tow	CV	Biomass (kg)/tow	CV	Mean weight (kg)	CV	Mean length (cm)	CV
1968	45.18	0.45	17.09	0.34	0.38	0.29	26.22	0.09
1969	46.43	0.26	19.69	0.29	0.42	0.10	28.64	0.04
1970	54.72	0.67	18.93	0.53	0.35	0.15	26.24	0.04
1971	157.23	0.28	71.56	0.30	0.46	0.07	29.54	0.02
1972	101.22	0.51	44.36	0.50	0.44	0.03	28.56	0.01
1973	44.35	0.31	25.30	0.32	0.57	0.07	30.90	0.02
1974	34.31	0.59	18.84	0.66	0.55	0.09	30.21	0.05
1975	38.93	0.32	17.61	0.35	0.45	0.05	28.06	0.02
1976	62.22	0.49	26.19	0.54	0.42	0.11	28.16	0.06
1977	25.06	0.26	11.59	0.26	0.46	0.17	28.90	0.05
1978	23.98	0.20	12.17	0.20	0.51	0.08	29.12	0.03
1979	61.41	0.32	32.21	0.33	0.52	0.07	29.69	0.02
1980	29.81	0.34	20.34	0.34	0.68	0.06	32.11	0.02
1981	33.04	0.69	18.31	0.69	0.55	0.01	30.45	0.01
1982	16.96	0.39	9.41	0.37	0.55	0.15	29.84	0.06
1983	9.85	0.36	6.07	0.41	0.62	0.11	30.37	0.04
1984	4.96	0.32	2.68	0.33	0.54	0.12	29.41	0.04
1985	11.72	0.39	6.61	0.40	0.56	0.08	29.99	0.03
1986	5.27	0.27	3.22	0.32	0.61	0.09	31.00	0.04
1987	24.50	0.80	12.93	0.84	0.53	0.05	30.25	0.02
1988	8.09	0.49	3.27	0.47	0.40	0.10	27.23	0.04
1989	7.81	0.28	2.98	0.36	0.38	0.14	25.85	0.06
1990	12.34	0.36	6.81	0.43	0.55	0.08	30.18	0.03
1991	9.47	0.32	4.26	0.38	0.45	0.14	27.23	0.07
1992	37.86	0.41	10.67	0.41	0.28	0.11	25.30	0.03
1993	35.50	0.45	17.50	0.50	0.49	0.07	29.33	0.02
1994	16.14	0.58	3.92	0.63	0.24	0.10	23.50	0.05
1995	7.23	0.32	1.92	0.40	0.27	0.27	22.86	0.09
1996	28.74	0.46	11.89	0.64	0.41	0.21	27.19	0.08
1997	212.02	0.77	34.04	0.71	0.16	0.11	21.20	0.02
1998	34.67	0.33	7.84	0.33	0.23	0.04	23.40	0.01
1999	76.05	0.33	19.02	0.29	0.25	0.14	23.92	0.04
2000	180.09	0.55	56.01	0.58	0.31	0.07	25.88	0.02
2001	101.61	0.46	37.97	0.54	0.37	0.12	27.61	0.04
2002	225.18	0.68	61.21	0.63	0.27	0.10	25.32	0.03
2003	109.15	0.41	33.34	0.43	0.31	0.04	26.03	0.02
2004	152.30	0.38	55.67	0.43	0.37	0.07	27.14	0.02
2005	145.34	0.53	46.26	0.53	0.32	0.06	26.24	0.02
2006	34.70	0.35	10.33	0.34	0.30	0.13	25.58	0.04
2007	122.25	0.33	35.10	0.35	0.29	0.11	25.32	0.03

Table N5. Estimated catch per tow, average weight and average length of Gulf of Main-Georges Bank Acadian redfish for all inshore and offshore strata (24, 26-30, 36-40) in the Autumn NEFSC bottom trawl survey.

Year	Numbers/tow	CV	Biomass (kg)/tow	CV	Mean weight (kg)	CV	Mean length (cm)	CV
1963	87.34	NA	24.11	NA	0.28	NA	25.04	NA
1964	116.26	0.68	53.64	0.75	0.46	0.09	29.66	0.06
1965	57.00	0.23	13.20	0.37	0.23	0.22	21.53	0.08
1966	93.84	0.34	29.27	0.45	0.31	0.16	24.27	0.07
1967	100.59	0.34	24.37	0.37	0.24	0.17	23.04	0.06
1968	143.45	0.41	40.43	0.43	0.28	0.07	24.76	0.03
1969	71.23	0.24	23.76	0.26	0.33	0.10	25.88	0.04
1970	93.98	0.23	32.96	0.19	0.35	0.12	26.12	0.04
1971	48.00	0.19	23.42	0.22	0.49	0.07	29.21	0.02
1972	55.57	0.17	24.63	0.19	0.44	0.05	28.40	0.02
1973	39.16	0.16	17.03	0.18	0.43	0.05	28.32	0.02
1974	48.30	0.22	24.16	0.30	0.50	0.13	28.47	0.05
1975	74.84	0.22	39.95	0.29	0.53	0.11	29.57	0.04
1976	28.85	0.31	15.29	0.39	0.53	0.12	29.71	0.05
1977	40.39	0.19	17.25	0.15	0.43	0.12	27.49	0.04
1978	45.21	0.17	20.74	0.16	0.46	0.05	28.67	0.02
1979	28.89	0.21	15.98	0.21	0.55	0.06	30.35	0.02
1980	20.58	0.28	12.63	0.31	0.61	0.10	30.68	0.03
1981	20.36	0.32	12.24	0.32	0.60	0.09	31.44	0.03
1982	9.18	0.46	3.48	0.27	0.38	0.27	26.31	0.09
1983	10.04	0.21	4.12	0.23	0.41	0.09	27.17	0.03
1984	7.77	0.42	3.93	0.38	0.51	0.08	28.86	0.02
1985	13.01	0.32	5.69	0.31	0.44	0.10	27.77	0.04
1986	26.05	0.39	8.01	0.34	0.31	0.13	25.04	0.04
1987	13.72	0.41	5.46	0.32	0.40	0.20	27.14	0.07
1988	12.43	0.41	6.33	0.57	0.51	0.19	27.50	0.06
1989	20.25	0.29	6.81	0.30	0.34	0.15	25.58	0.05
1990	35.53	0.34	12.16	0.33	0.34	0.11	26.01	0.03
1991	19.06	0.34	8.36	0.45	0.44	0.17	28.01	0.05
1992	22.37	0.26	8.09	0.29	0.36	0.09	26.90	0.03
1993	35.62	0.31	11.20	0.33	0.31	0.09	24.90	0.03
1994	20.86	0.32	5.94	0.43	0.28	0.16	24.24	0.05
1995	33.22	0.25	4.65	0.24	0.14	0.11	19.92	0.02
1996	169.64	0.35	30.63	0.33	0.18	0.11	21.83	0.03
1997	65.02	0.30	18.94	0.39	0.29	0.15	24.63	0.05
1998	116.95	0.42	31.72	0.45	0.27	0.08	24.47	0.03
1999	82.48	0.23	22.86	0.24	0.28	0.05	24.87	0.02
2000	104.43	0.27	26.16	0.29	0.25	0.07	24.22	0.03
2001	89.62	0.23	28.17	0.25	0.31	0.05	26.23	0.02
2002	185.19	0.31	41.88	0.33	0.23	0.09	23.77	0.04

2003	250.94	0.47	65.49	0.49	0.26	0.08	25.36	0.02
2004	127.29	NA	36.63	NA	0.29	NA	24.89	NA
2005	166.07	0.21	46.95	0.23	0.28	0.04	25.54	0.02
2006	183.43	0.31	50.22	0.30	0.27	0.05	24.96	0.02
2007	170.03	0.23	50.39	0.25	0.30	0.08	25.59	0.03

Table N6. Weightings for likelihood components in RED and STATCAM models. Red indicates changes from the Base models.

	RED BASE	Alternate 1	STATCAM BASE	Alternate 1	Alternate 2	Alternate 3
CV log Rec.	NA	NA	1.0	0.1	0.1	0.1
W Rec.	10.0	1000.0	10.0	1000.0	100.0	231.0
CV Log Catch Weight	NA	NA	0.1	0.1	0.1	0.1
CV log F	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
Weight F	NA	NA	1.0	0.1	100.0	100.0
Weight CPUE	1.0	0.01	1.0	0.01	0.0001	0.0001
Weight Age Comp., catch Effective n	10.0	10.0	1.0	1.0	1.0	1.0
Pa catch Weight	10.0	10.0	10.0	10.0	10.0	10.0
Fall Survey Weight	200.0	200.0	200.0	200.0	200.0	200.0
Age Comp. Fall Survey Effective n	1000.0	1000.0	25.0	25.0	100.0	100.0
Age Comp. Fall Survey Weight	1.0	1.0	1.0	1.0	1.0	1.0
Spring Survey Effective n	100.0	100.0	100.0	100.0	100.0	100.0
Spring Survey Weight	1000.0	1000.0	25.0	25.0	100.0	100.0
Age Comp. Spring Survey Effective n	1.0	1.0	1.0	1.0	1.0	1.0
Age Comp. Spring Survey Weight	100.0	100.0	100.0	100.0	100.0	100.0
Fishery Selectivity	100.0	100.0	100.0	100.0	100.0	100.0

Table N7. Assumptions made for ASAP model implementation for Gulf of Maine-Georges Bank Acadian Redfish.

Unestimated Parameter	Assumed Value
CV Recruitment residuals	0.2 for years with no age sampling and 0.4 for years without age sampling (Alternative 1) or 0.1 for years with no age sampling and 0.8 for years without age sampling (Alternative 2)
CV NAA in 1913	0.01
CV Catch	0.01 or estimate provided by variance estimation for discards where available
CV Survey Indices	Design-based estimates where available, 0.3 otherwise
CV of Survey/Fishery Selectivity Parameters	0.5
Fishery effective sample size (input)	200
Survey effective sample size (input)	100
Natural Mortality	0.05
Fraction of year at Spawning	0.4
Fraction of year at Spring Survey	0.375
Fraction of year at Fall Survey	0.875

Table N8. Parameter estimates (and standard errors) from ASAP alternatives 1, 2 and 3.

Parameter	Alternative 1	Alternative 2	Alternative 3
Steepness	0.67338 (0.017798)	0.60743 (0.013866)	0.64003 (0.014050)
Unexploited Spawning Biomass (mt)	584,785.3 (16,106.74)	652,783.0 (9,768.90)	643,707.7 (9,385.90)
MSY	9734.8 (149.43)	9857.7 (169.86)	10,237 (166.34)
SB _{MSY} (mt)	182,880 (2868.5)	216,850 (3757.8)	207,580 (3421.2)
F _{MSY}	0.042277 (0.00018461)	0.036036 (0.00015197)	0.039110 (0.00016463)
2006 Spawning Biomass (mt)	151,800 (12,868)	182,360 (15,570)	215,720 (18,644)
2006 F	0.0033707 (0.00034051)	0.0028253 (0.00028648)	0.0024045 (0.00024582)
Fishery selectivity (Age 1)	0.028394 (0.0063316)	0.028904 (0.0064588)	0.028605 (0.0063884)
Fishery selectivity (Age 2)	0.028197 (0.0062798)	0.028559 (0.0063687)	0.028437 (0.0063421)
Fishery selectivity (Age 3)	0.031721 (0.0065592)	0.031696 (0.0065520)	0.031582 (0.0065301)
Fishery selectivity (Age 4)	0.052026 (0.0092523)	0.051820 (0.0092053)	0.051160 (0.0090884)
Fishery selectivity (Age 5)	0.23935 (0.025402)	0.23965 (0.025365)	0.23320 (0.024709)
Fishery selectivity (Age 6)	0.54547 (0.043123)	0.54442 (0.042864)	0.53106 (0.041797)
Fishery selectivity (Age 7)	0.64715 (0.050139)	0.62386 (0.047902)	0.62370 (0.047867)
Fishery selectivity (Age 8)	0.85412 (0.063581)	0.81799 (0.060047)	0.83679 (0.061071)
Fishery selectivity (Age 9)	1.0000 (0.000060564)	1.0000 (0.00022226)	1.0000 (0.00016403)
Spring Survey selectivity (Age 1)	0.71953 (0.27940)	0.71122 (0.27514)	0.69485 (0.26678)
Spring Survey selectivity (Age 2)	0.65305 (0.17378)	0.64145 (0.17039)	0.61778 (0.16323)
Spring Survey selectivity (Age 3)	0.77826 (0.14819)	0.76545 (0.14590)	0.73053 (0.13881)
Spring Survey selectivity (Age 4)	0.73325 (0.10704)	0.73238 (0.10721)	0.70873 (0.10354)
Spring Survey selectivity (Age 5)	0.53092 (0.079958)	0.53799 (0.081287)	0.52258 (0.078760)
Spring Survey selectivity (Age 6)	0.69453 (0.082463)	0.70998 (0.084474)	0.68927 (0.081867)
Spring Survey selectivity (Age 7)	0.88581 (0.096192)	0.90992 (0.099285)	0.88323 (0.096192)

Spring Survey selectivity (Age 8)	0.75725 (0.087847)	0.76027 (0.088510)	0.75621 (0.088312)
Spring Survey selectivity (Age 9)	0.71535 (0.091112)	0.70603 (0.090113)	0.72417 (0.093360)
Fall Survey selectivity (Age 1)	1.0000 (0.00014633)	1.0000 (0.00018891)	1.0000 (0.00023536)
Fall Survey selectivity (Age 2)	0.92952 (0.13239)	0.84442 (0.12002)	0.79864 (0.11326)
Fall Survey selectivity (Age 3)	0.96804 (0.096861)	0.89082 (0.089166)	0.84933 (0.084926)
Fall Survey selectivity (Age 4)	1.0000 (0.0000074952)	1.0000 (0.0000081514)	1.0000 (0.0000086247)
Fall Survey selectivity (Age 5)	1.0000 (0.0000064994)	1.0000 (0.0000069428)	1.0000 (0.0000072708)
Fall Survey selectivity (Age 6)	1.0000 (0.000013815)	1.0000 (0.000015446)	1.0000 (0.000016847)
Fall Survey selectivity (Age 7)	1.0000 (0.000055750)	1.0000 (0.000068814)	1.0000 (0.000094718)
Fall Survey selectivity (Age 8)	0.93451 (0.064020)	0.92998 (0.063838)	0.92944 (0.063781)
Fall Survey selectivity (Age 9)	0.83734 (0.063523)	0.83928 (0.063863)	0.84954 (0.064777)

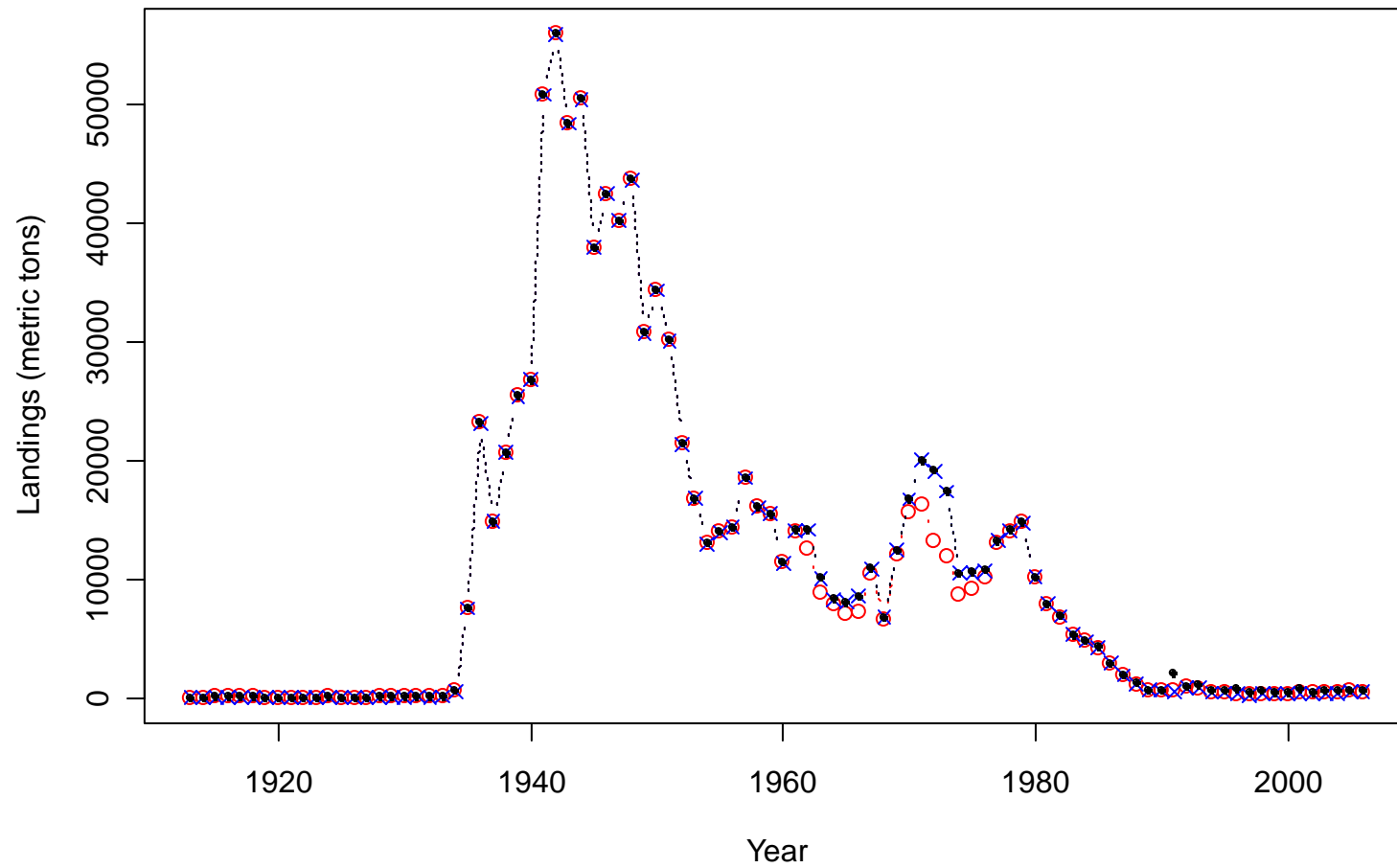


Figure N1. Annual landings (mt) of Gulf of Maine-Georges Bank Acadian redfish between 1913-2006 for US fleet only (red), US and foreign fleets combined (blue) and total landings combined with annual discard estimates between 1989-2006 (black).

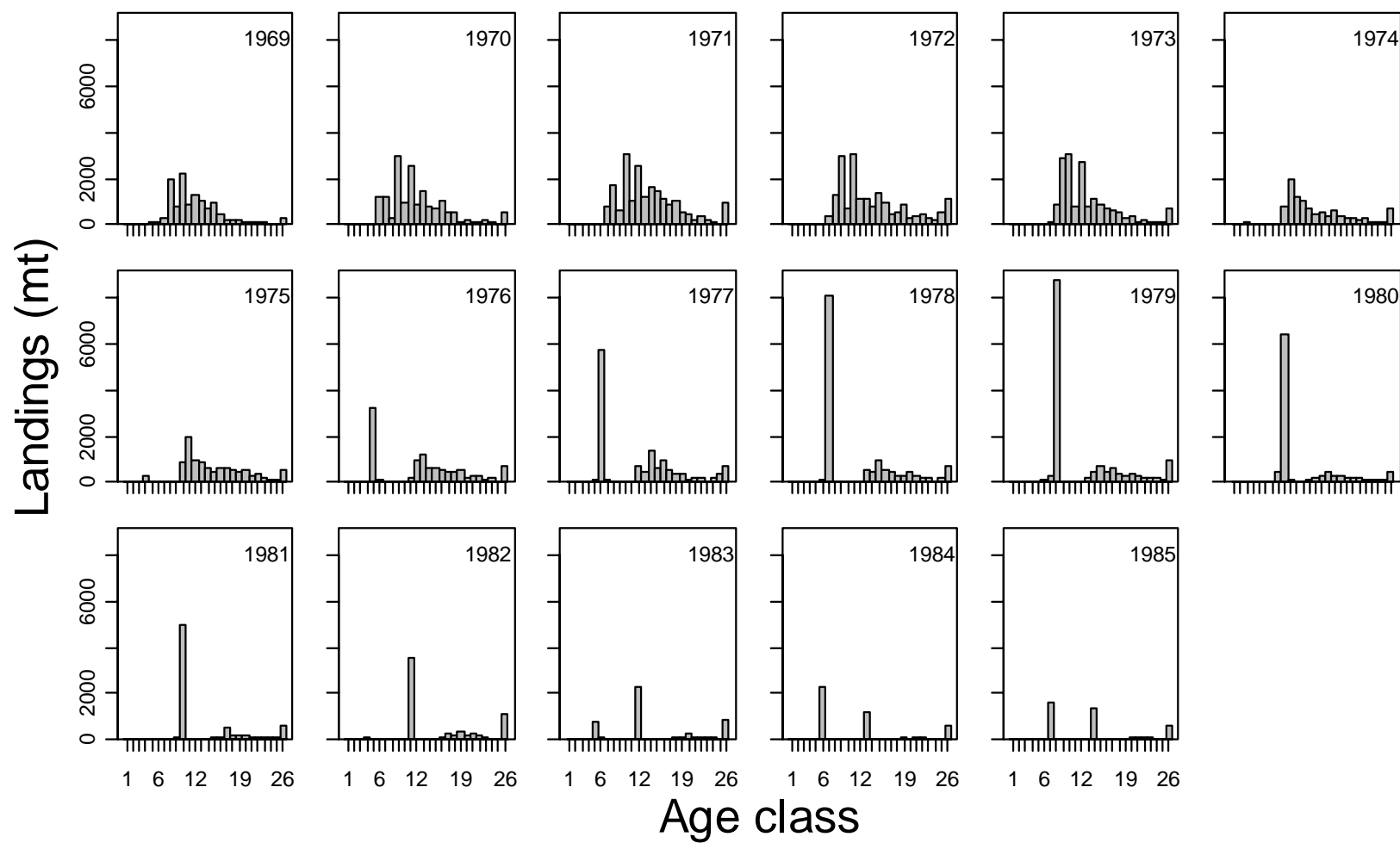


Figure N2. Estimated annual landings (mt) at age for Gulf of Maine-Georges Bank Acadian redfish between 1969-1985.

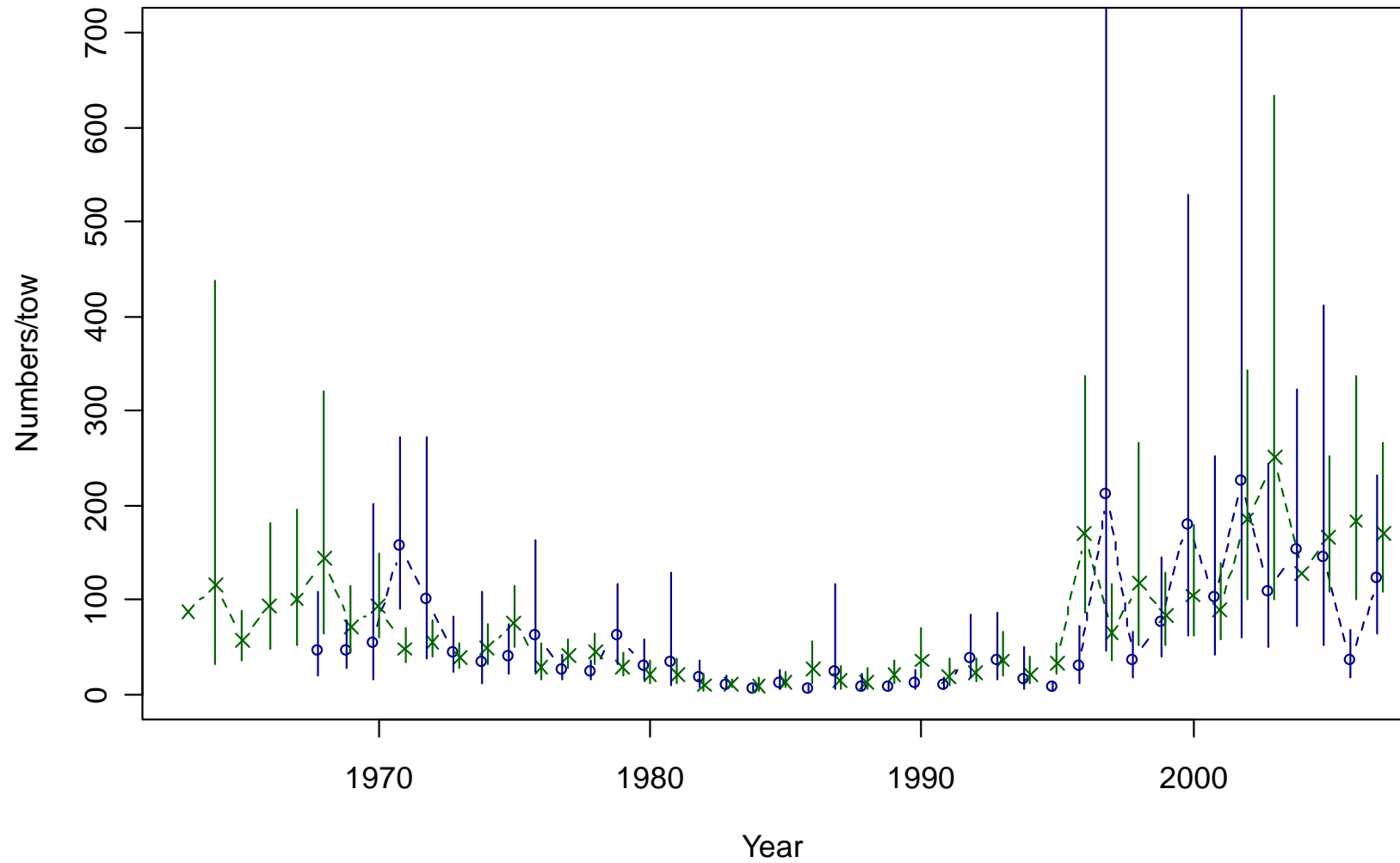


Figure N3. Estimated numbers per tow for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring (blue, circle) and autumn (green, x) survey over all inshore and offshore strata. Vertical bars represent approximate 95% confidence intervals.

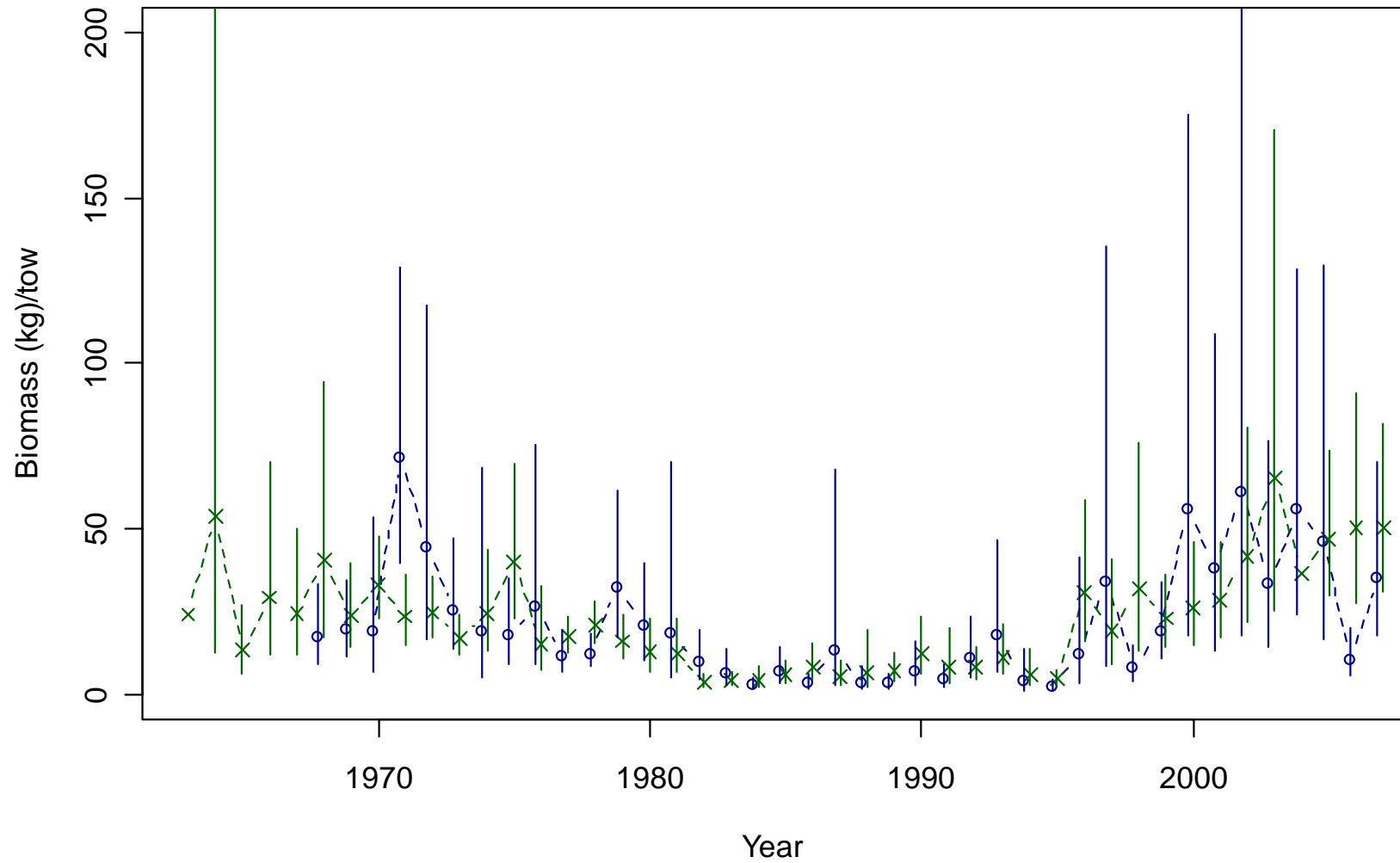


Figure N4. Estimated biomass (kg) per tow for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring (blue, circle) and autumn (green, x) survey over all inshore and offshore strata. Vertical bars represent approximate 95% confidence intervals.

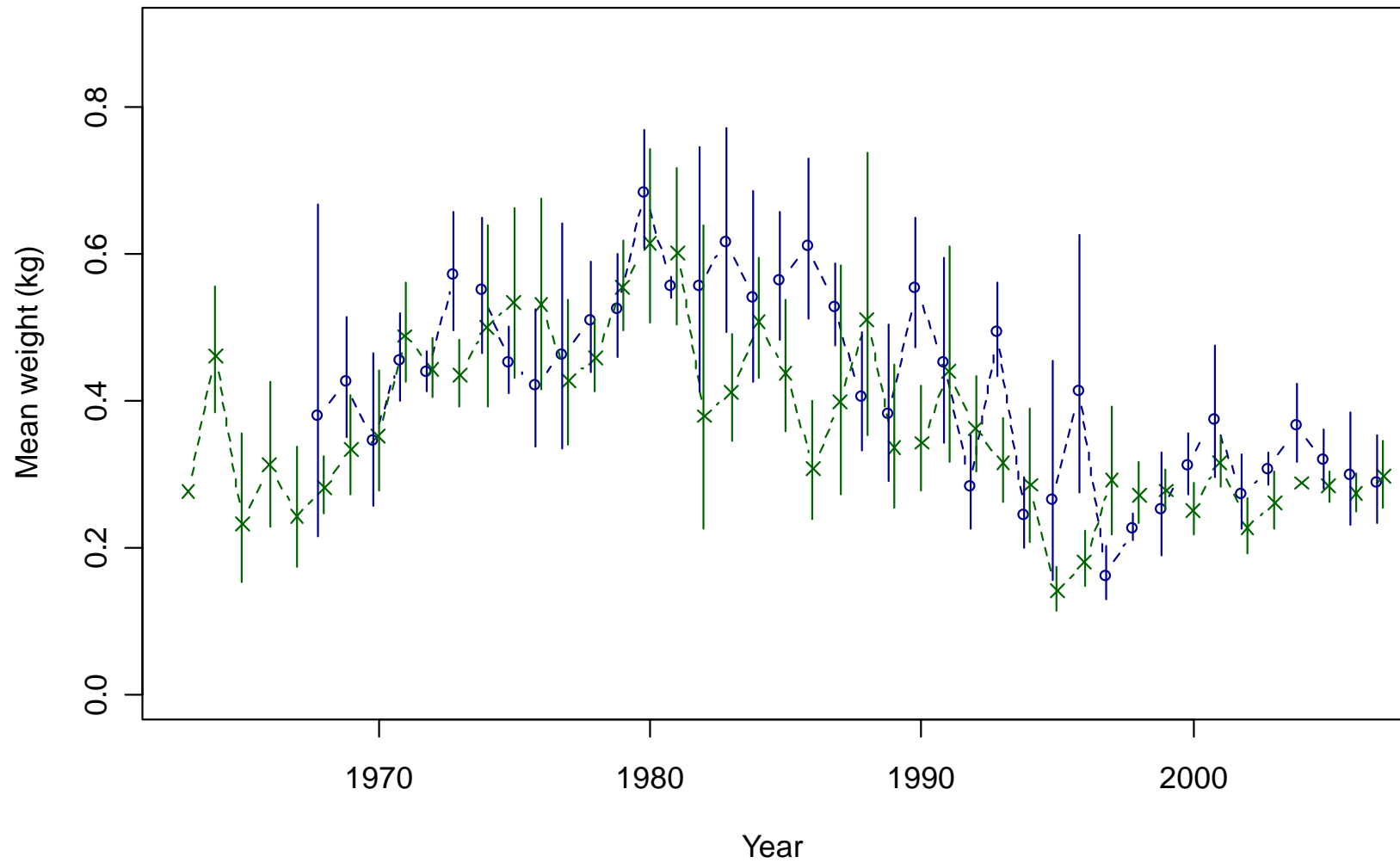


Figure N5. Estimated mean weight (kg) of Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring (blue, circle) and autumn (green, x) survey over all inshore and offshore strata. Vertical bars represent approximate 95% confidence intervals.

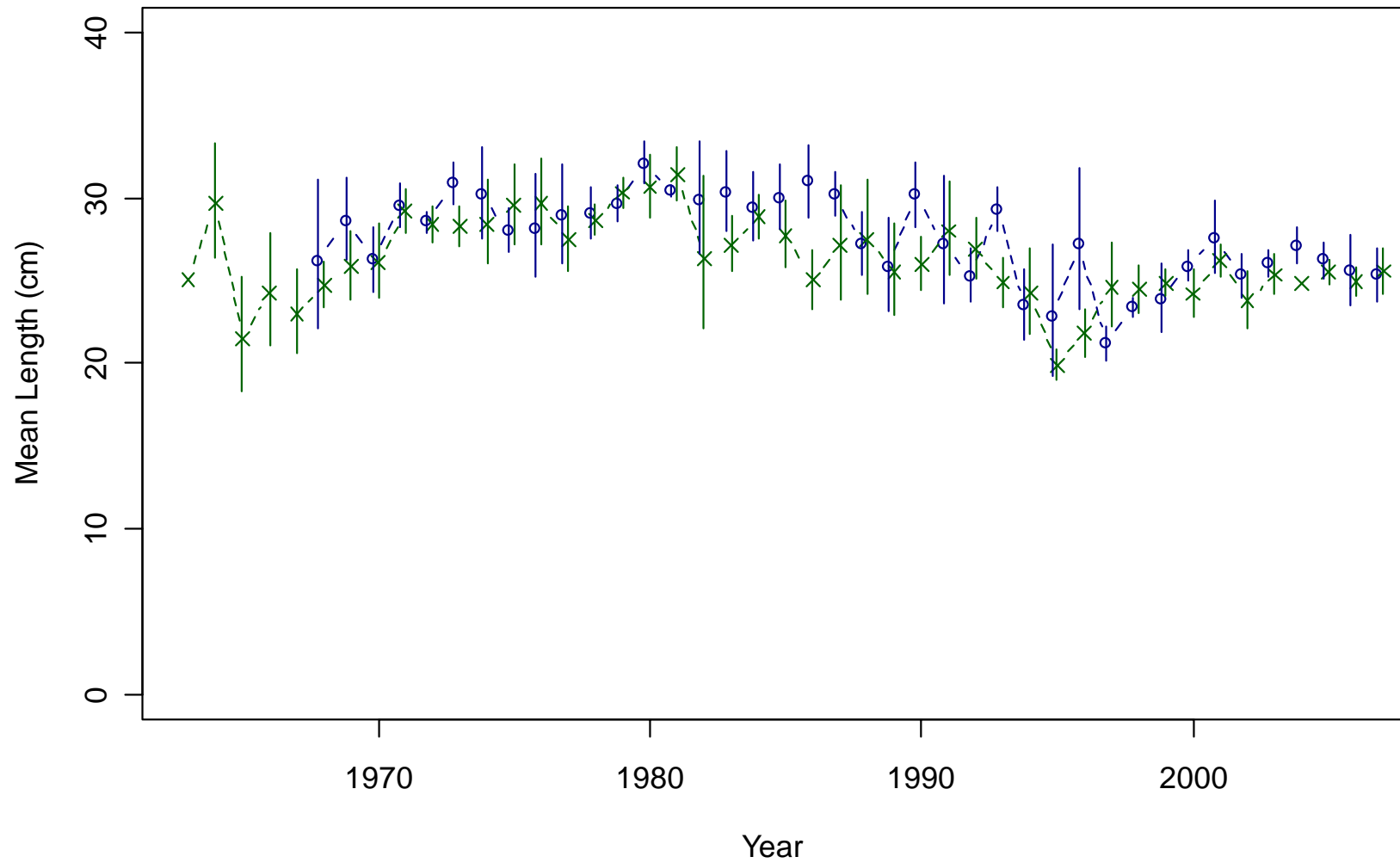


Figure N6. Estimated mean length (cm) of Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring (blue, circle) and autumn (green, x) survey over all inshore and offshore strata. Vertical bars represent approximate 95% confidence intervals.

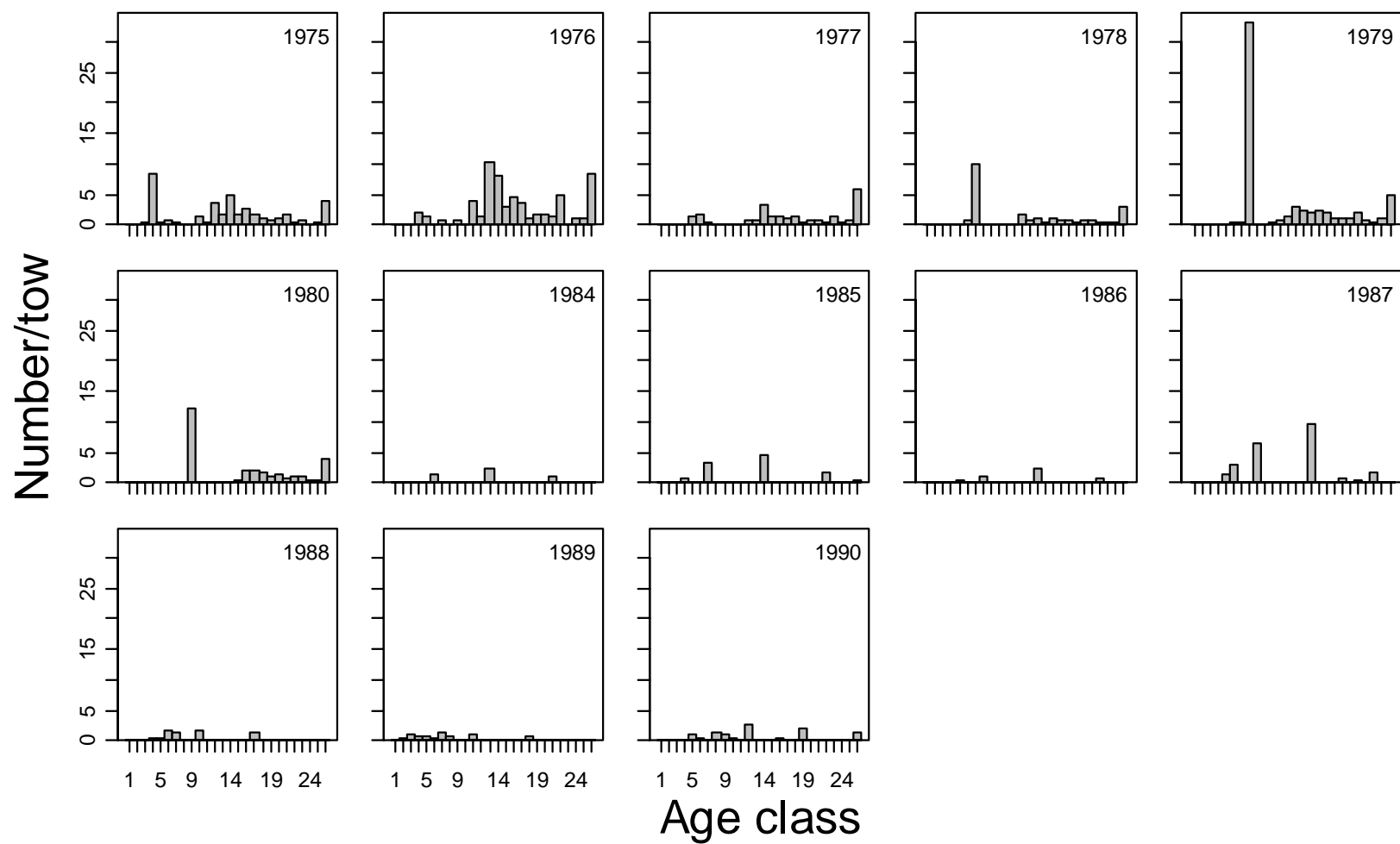


Figure N7. Estimated Numbers at age per tow for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring survey.

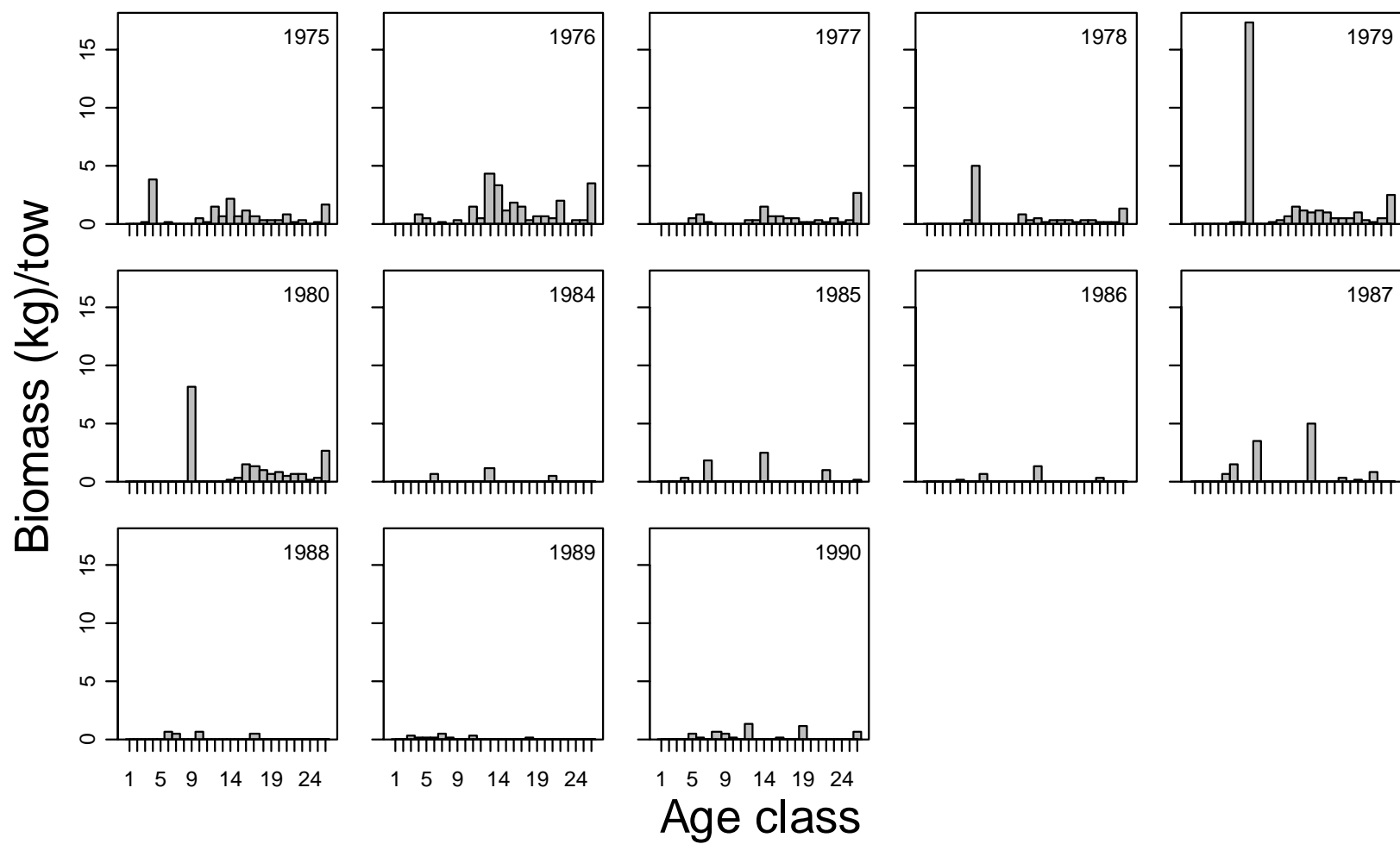


Figure N8. Estimated Biomass (kg) at age per tow for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC spring survey.

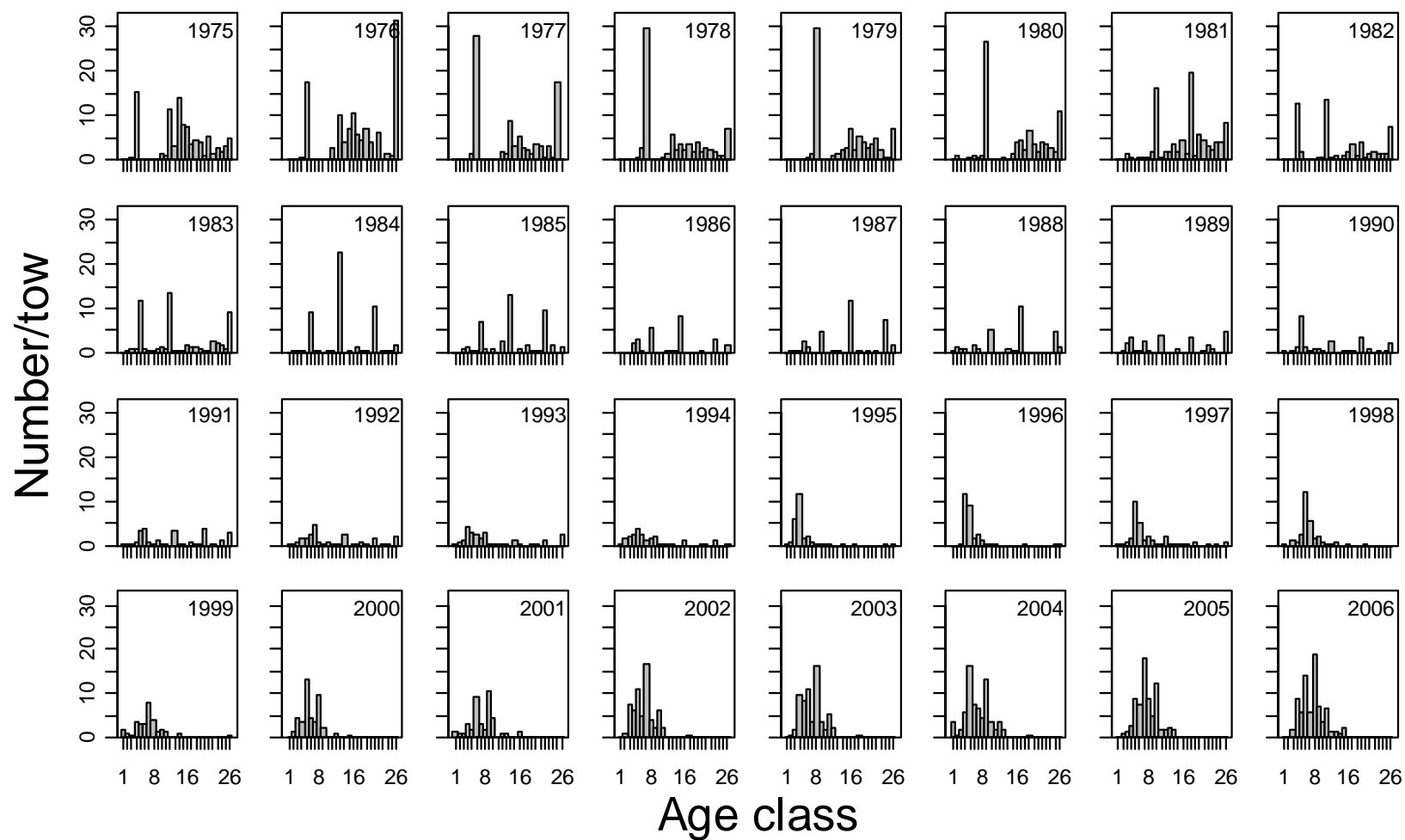


Figure N9. Estimated Numbers at age per tow for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC fall survey.

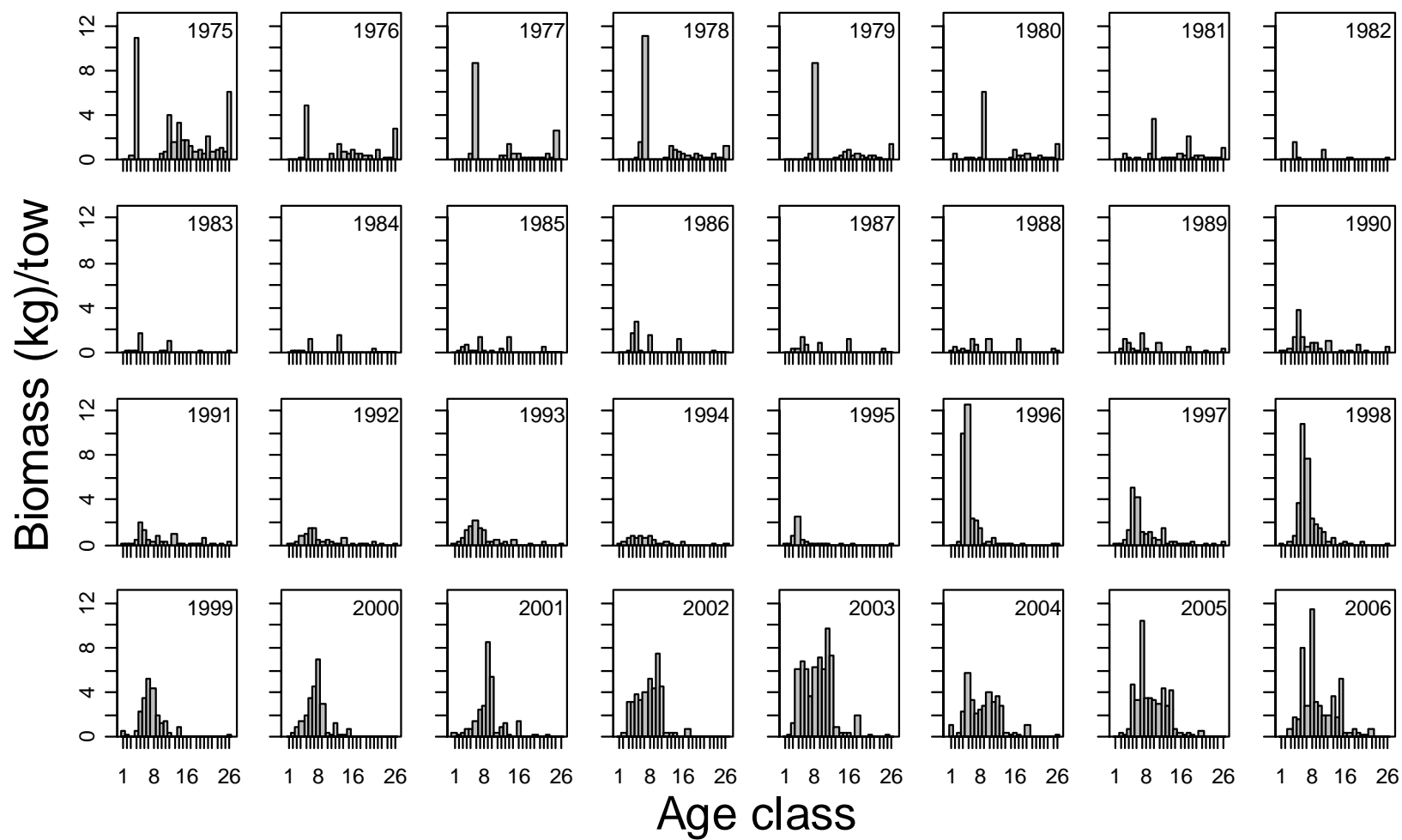


Figure N10. Estimated Biomass (kg) at age per tow for Gulf of Maine-Georges Bank Acadian redfish in the NEFSC fall survey.

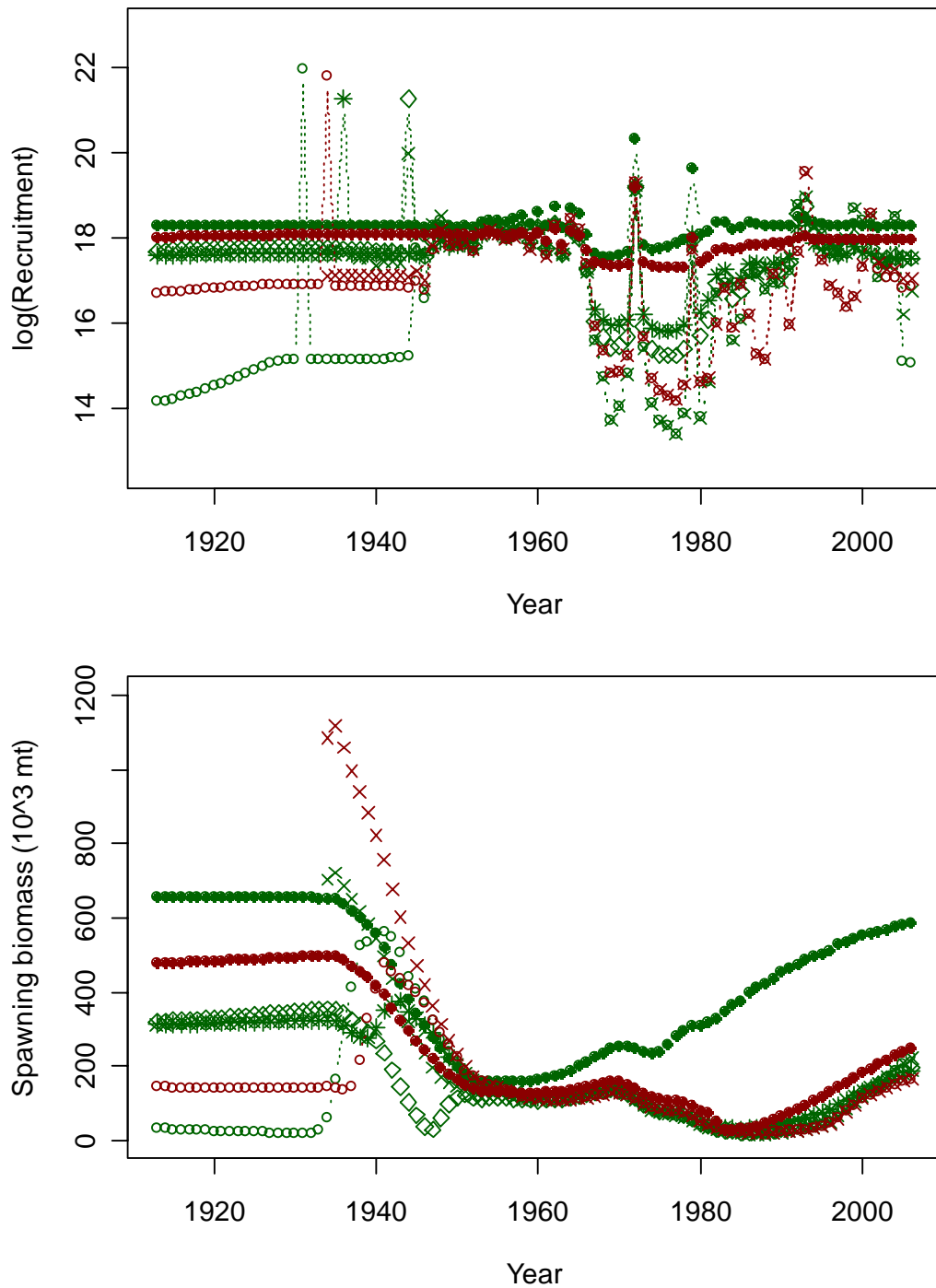


Figure N11. Estimates of Annual (log) numbers of age 1 recruits and spawning biomass provided by RED (red) and STATCAM (green) models. Results are for the base models with landings between 1934 – 2006 (x) and the base models (open circle), Alternate 1 models (closed circle) and Alternate 2 (diamond) and 3 (*) models for STATCAM using landings between 1913-2006.

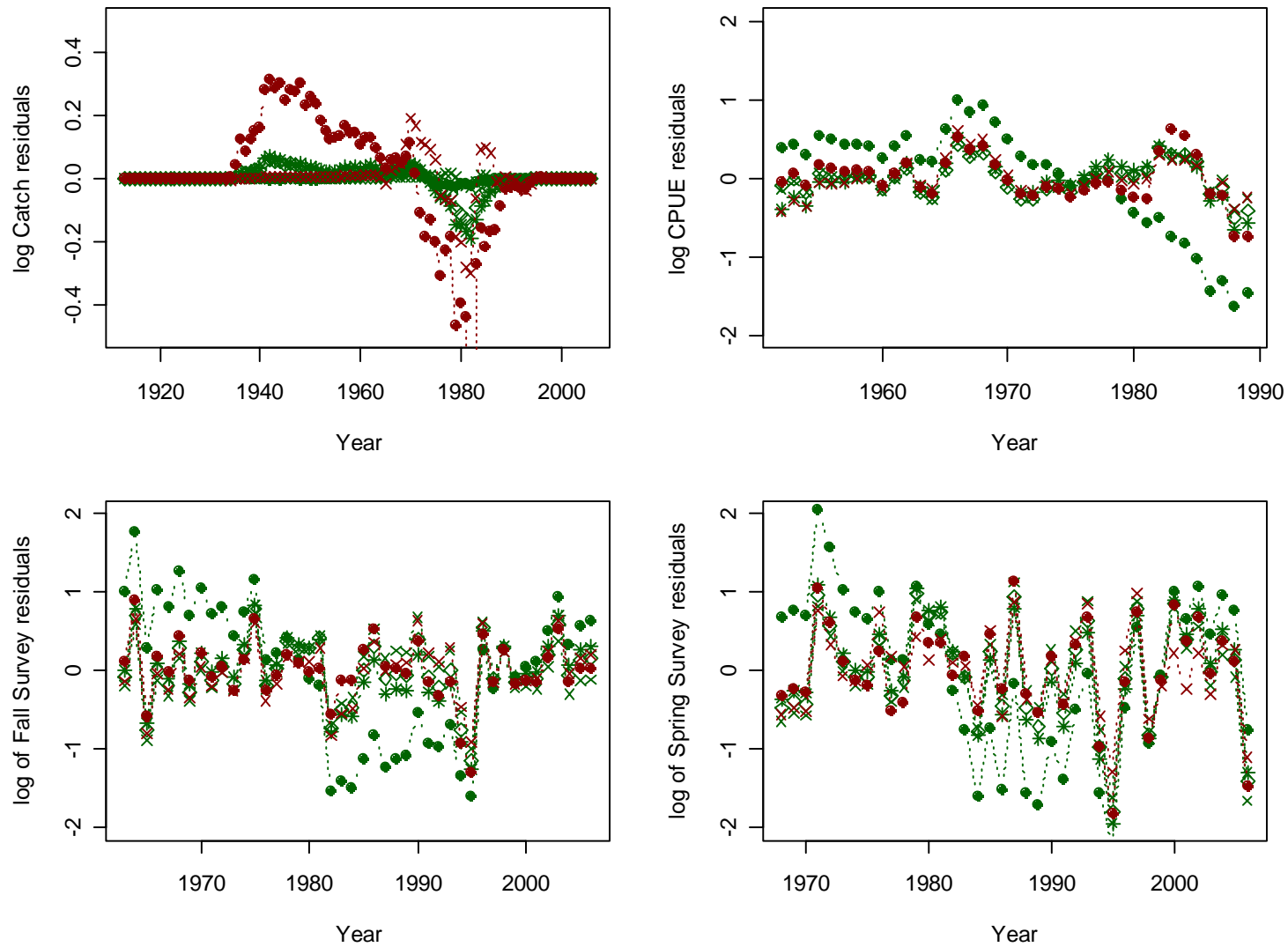


Figure N12. Model residuals of log catch, CPUE, and spring and fall survey biomass per tow produced by RED (red) and STATCAM (green) models. Results are for the base models with landings between 1934 – 2006 (x) and Alternate 1 models (closed circle) and Alternate 2 (diamond) and 3 (*) models for STATCAM using landings between 1913-2006.

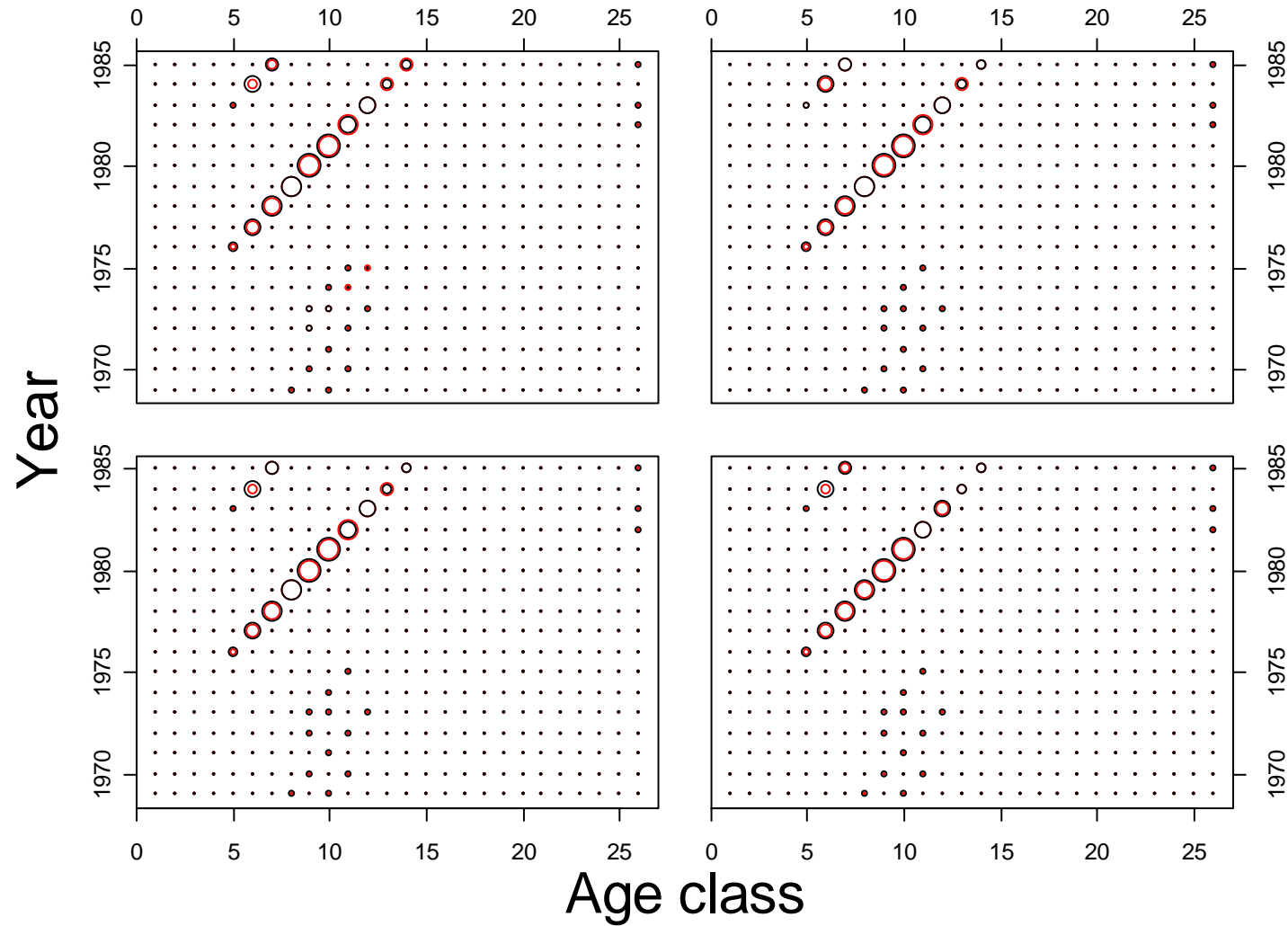


Figure N13. Proportions at age in the landings observed (black) and estimated (red) by RED and STATCAM models. Results are for the base models with landings between 1934 – 2006 (RED top left, STATCAM, top right) and STATCAM Alternate 2 (bottom left) and Alternate 3 (bottom right) models using landings between 1913-2006.

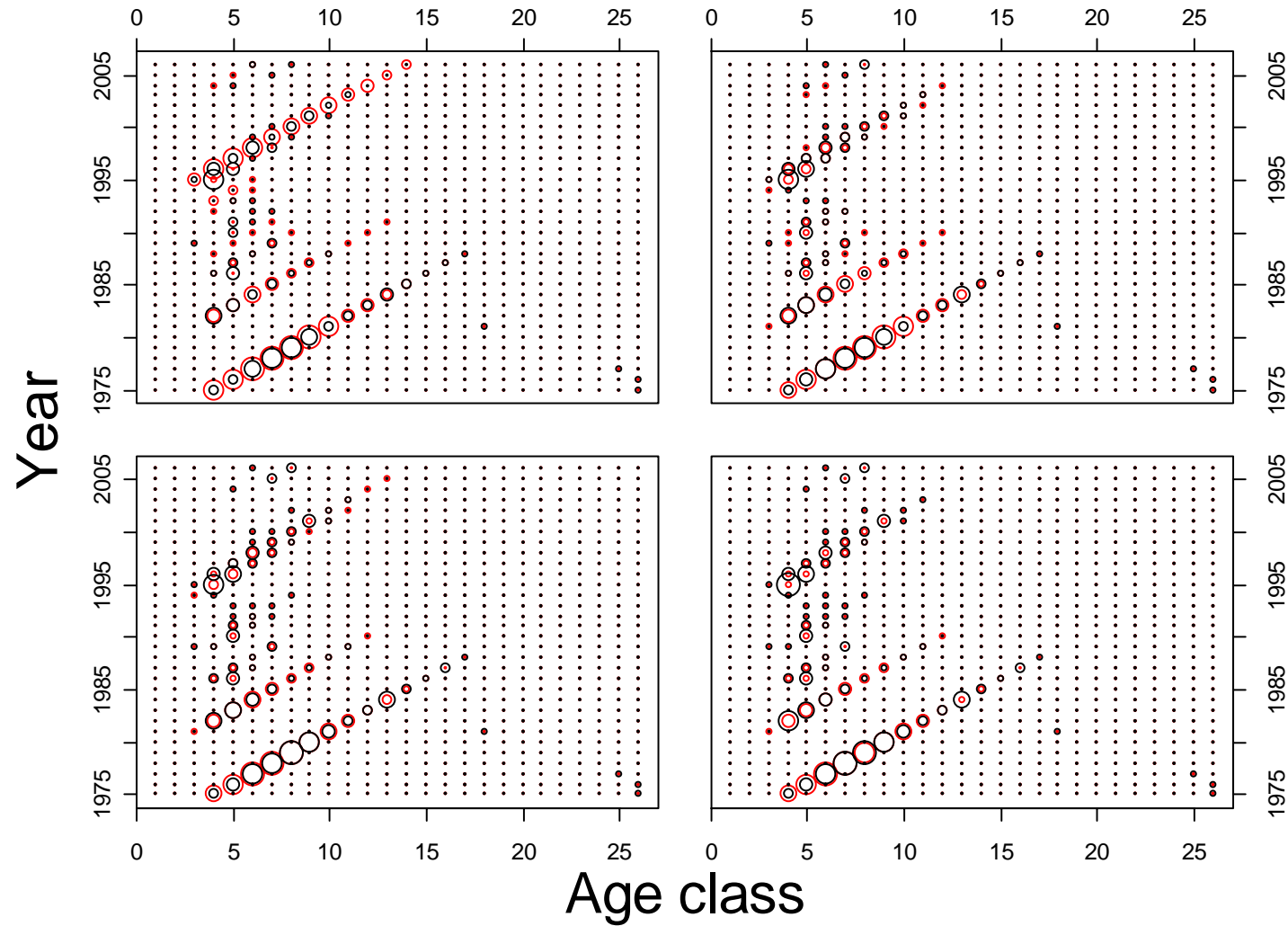


Figure N14. Proportions at age in fall survey observed (black) and estimated (red) by RED and STATCAM models. Results are for the base models with landings between 1934 – 2006 (RED top left, STATCAM, top right) and STATCAM Alternate 2 (bottom left) and Alternate 3 (bottom right) models using landings between 1913-2006.

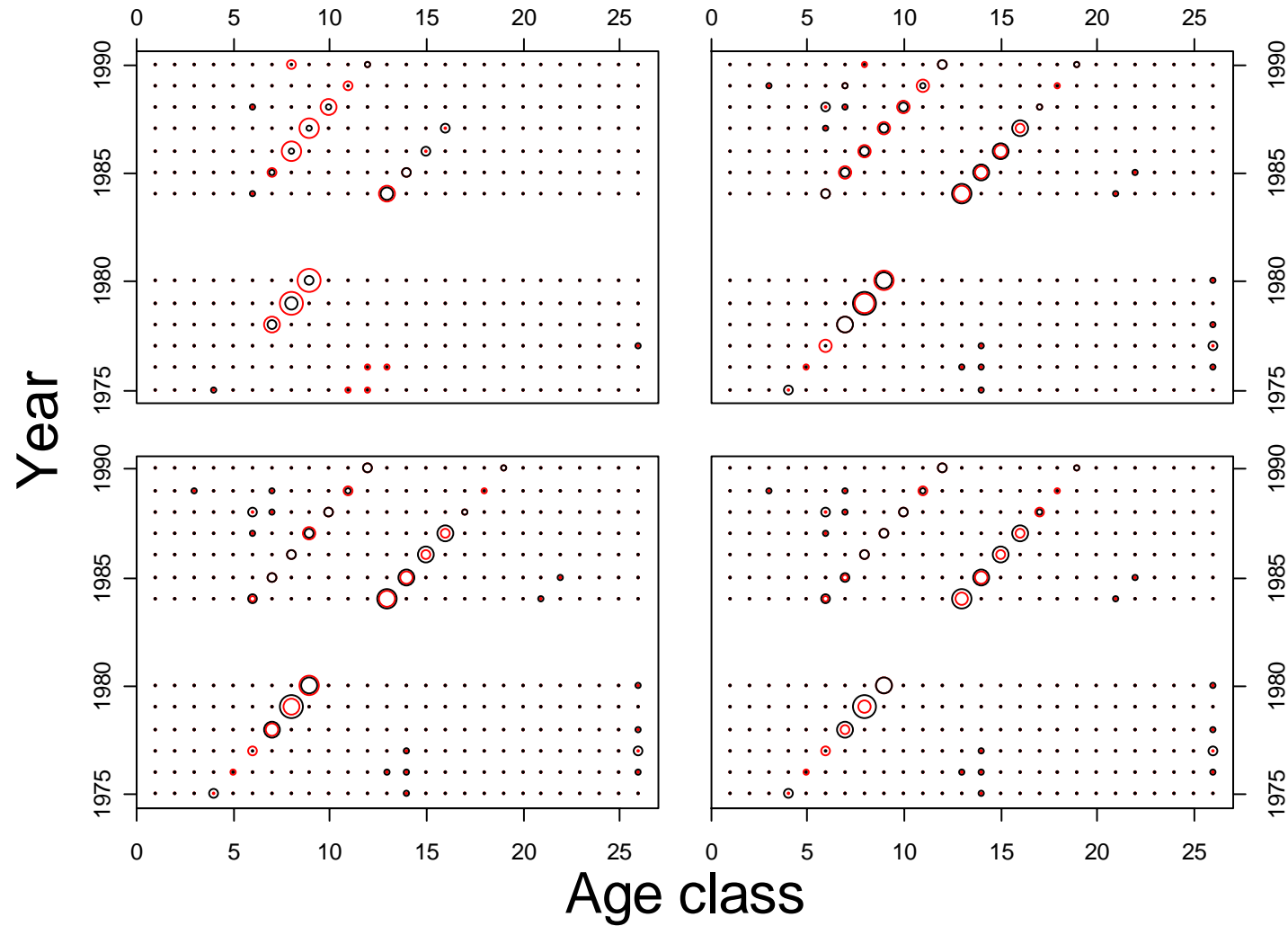


Figure N15. Proportions at age in spring survey observed (black) and estimated (red) by RED and STATCAM models. Results are for the base models with landings between 1934 – 2006 (RED top left, STATCAM, top right) and STATCAM Alternate 2 (bottom left) and Alternate 3 (bottom right) models using landings between 1913-2006.

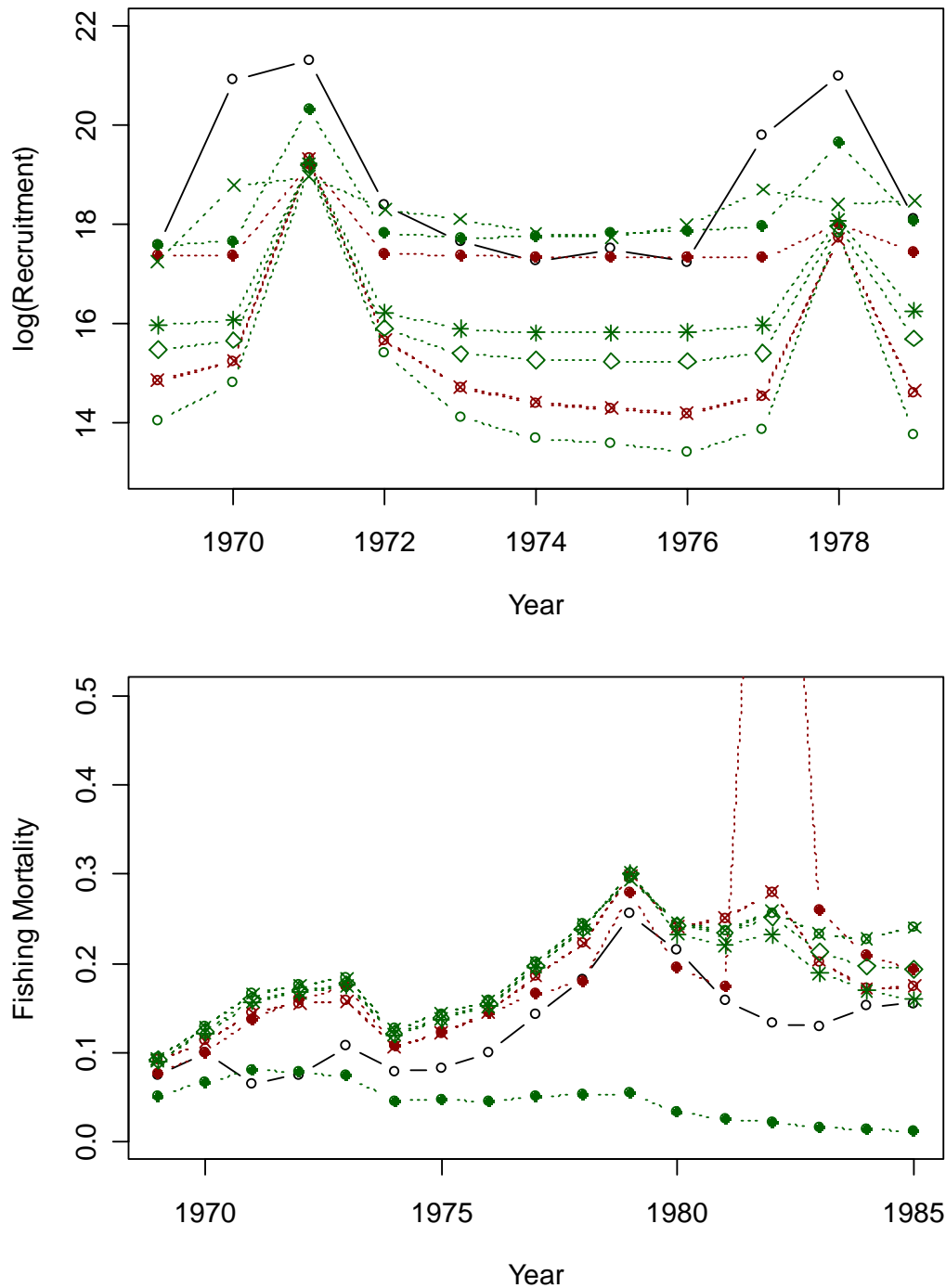


Figure N16. Estimates of Annual (log) numbers of age 1 recruits and spawning biomass provided by RED (red), STATCAM (green) and FSCTPD (black) models. Results are for the base models with landings between 1934 – 2006 (x) and the base models (open circle), Alternate 1 models (closed circle) and Alternate 2 (diamond) and 3 (*) models for STATCAM using landings between 1913-2006.

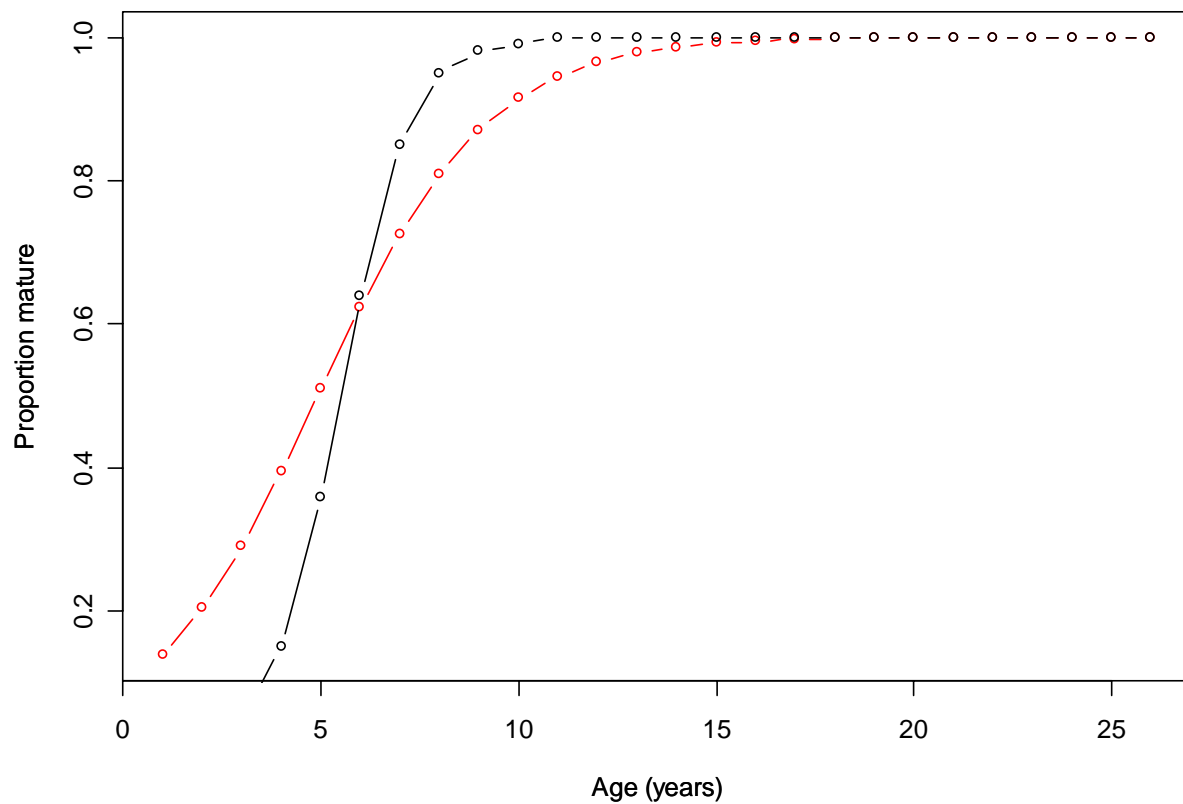


Figure N17. Proportion mature at age assumed in previous assessments (black) and estimated for females (red line) maturity and age data from Gulf of Maine-Georges Bank Acadian redfish caught in spring bottom trawl surveys.

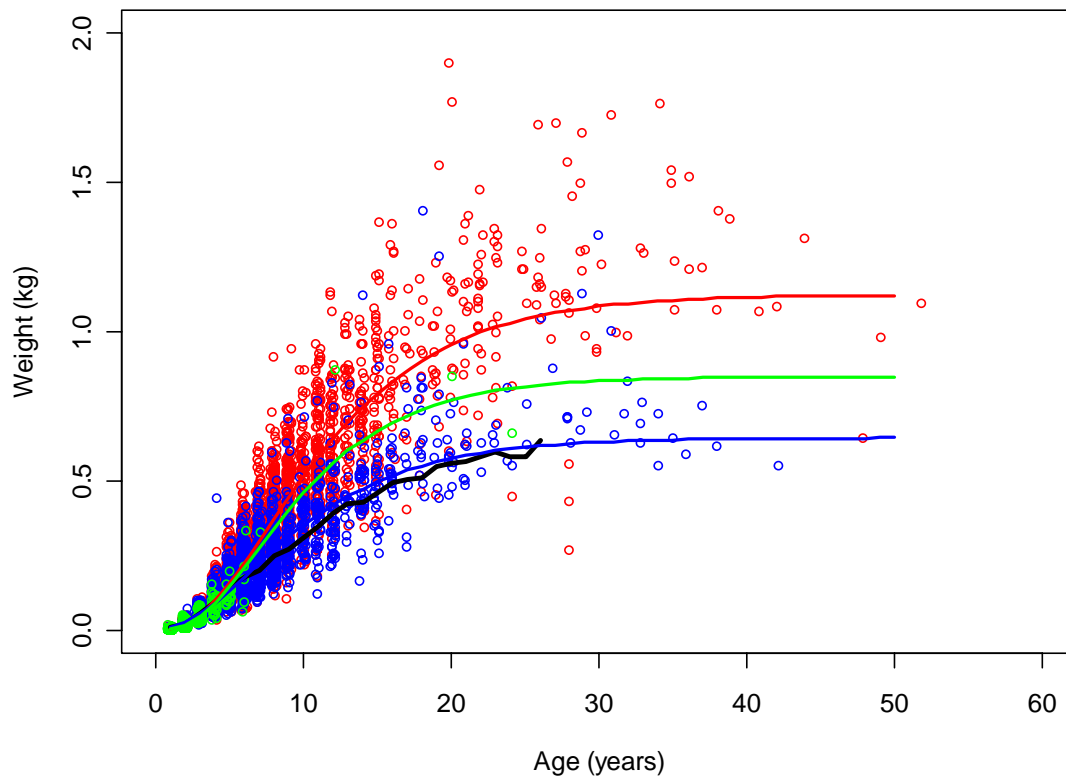


Figure N18. Weight at age assumed in previous assessments (black line) and estimated for females (red line), males (blue line) and combined (green line) from length, weight and age data from Gulf of Maine-Georges Bank Acadian redfish caught in bottom trawl surveys. Red, blue and green points represent female, male and unknown sex individuals.

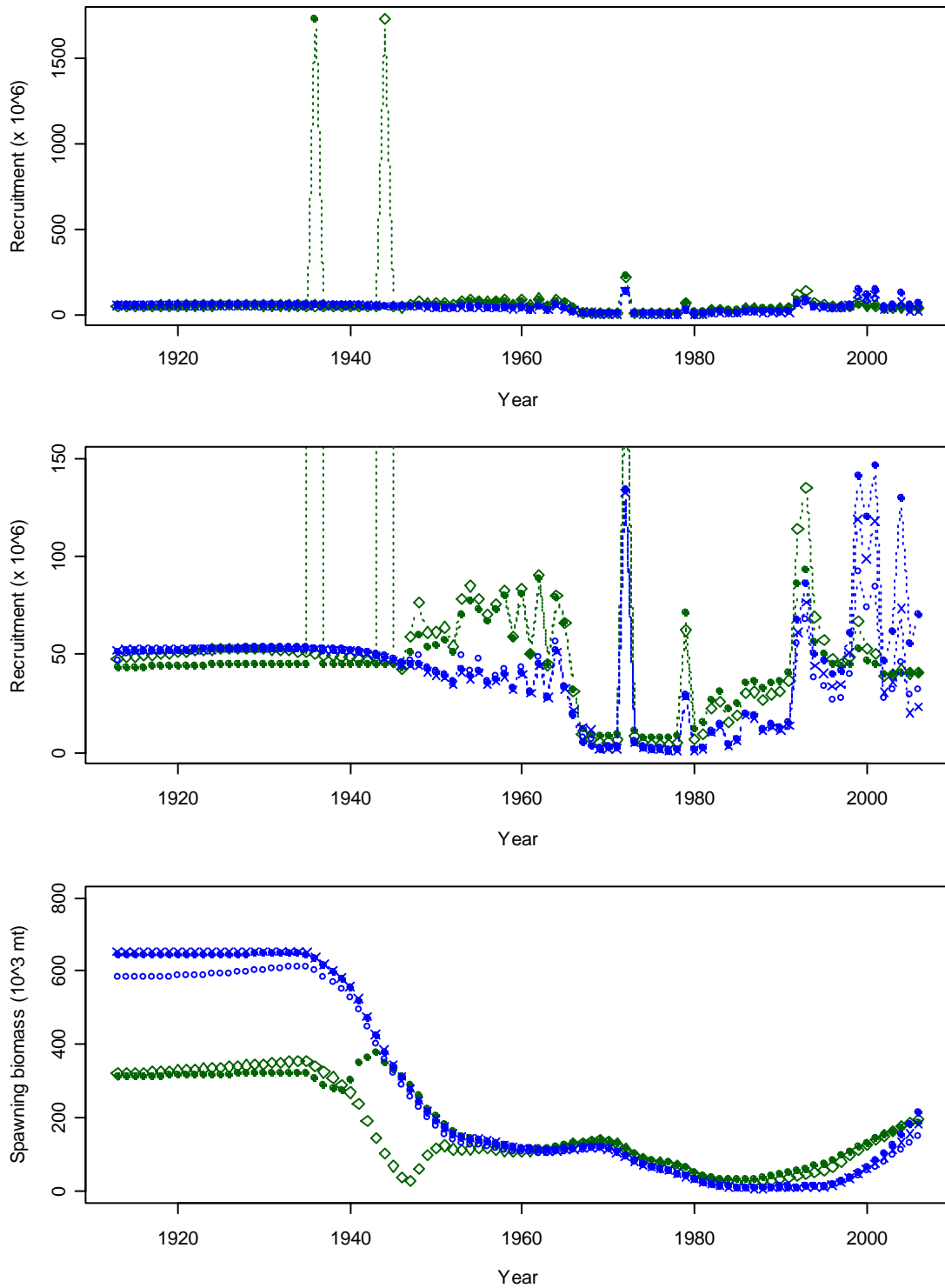


Figure N19. Recruitment (top and middle) and spawning biomass estimates from the STATCAM alternatives (green) 2 (diamond) and 3 (closed circle) and ASAP (blue) alternatives 1 (open circle), 2 (x) and 3 (closed circle).

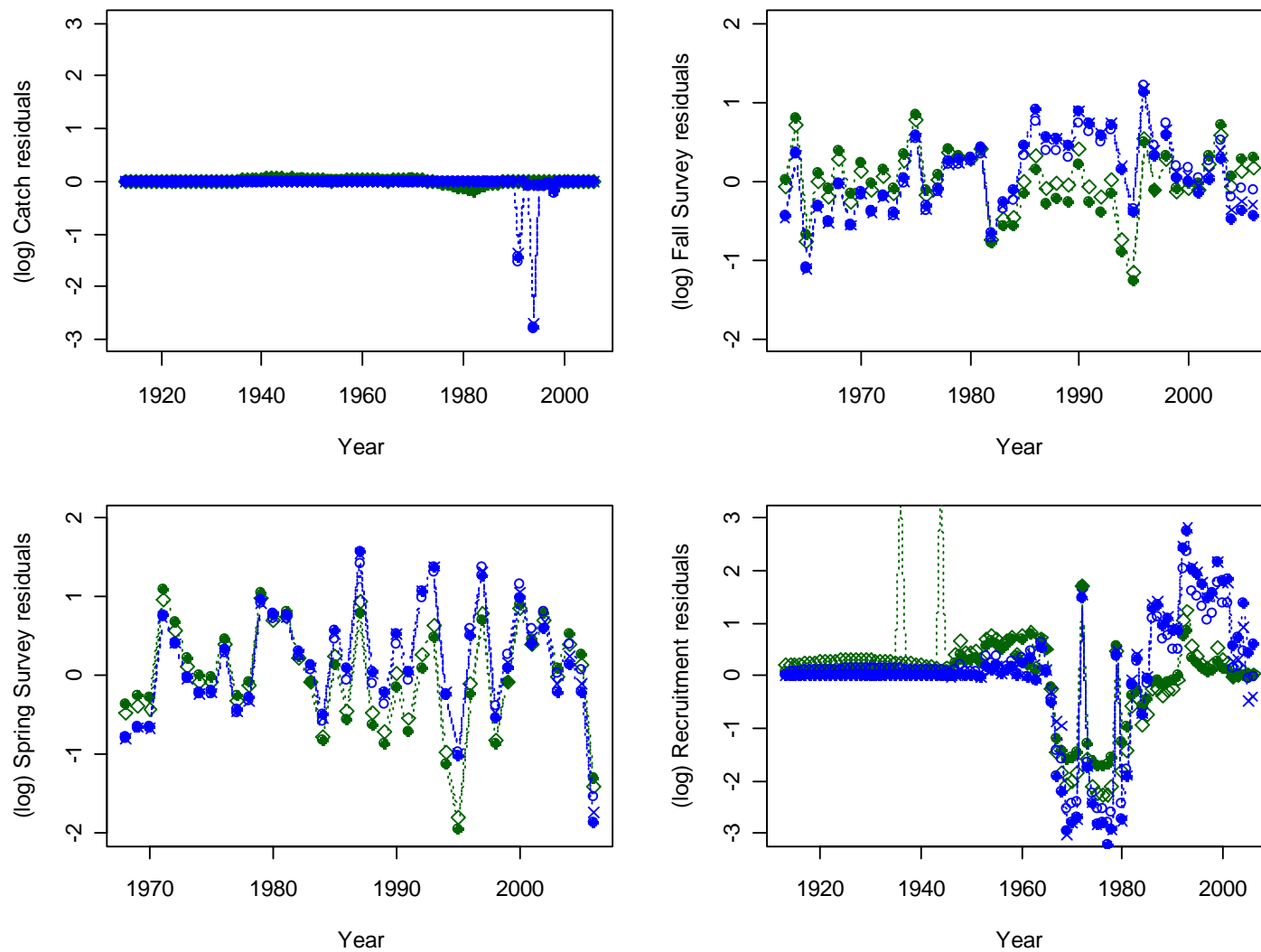


Figure N20. Model residuals for log catch, fall and spring survey biomass per tow and recruitment produced by STATCAM. STATCAM (green) alternatives 2 (diamond) and 3 (closed circle) and ASAP (blue) alternatives 1 (open circle), 2 (x) and 3 (open circle).

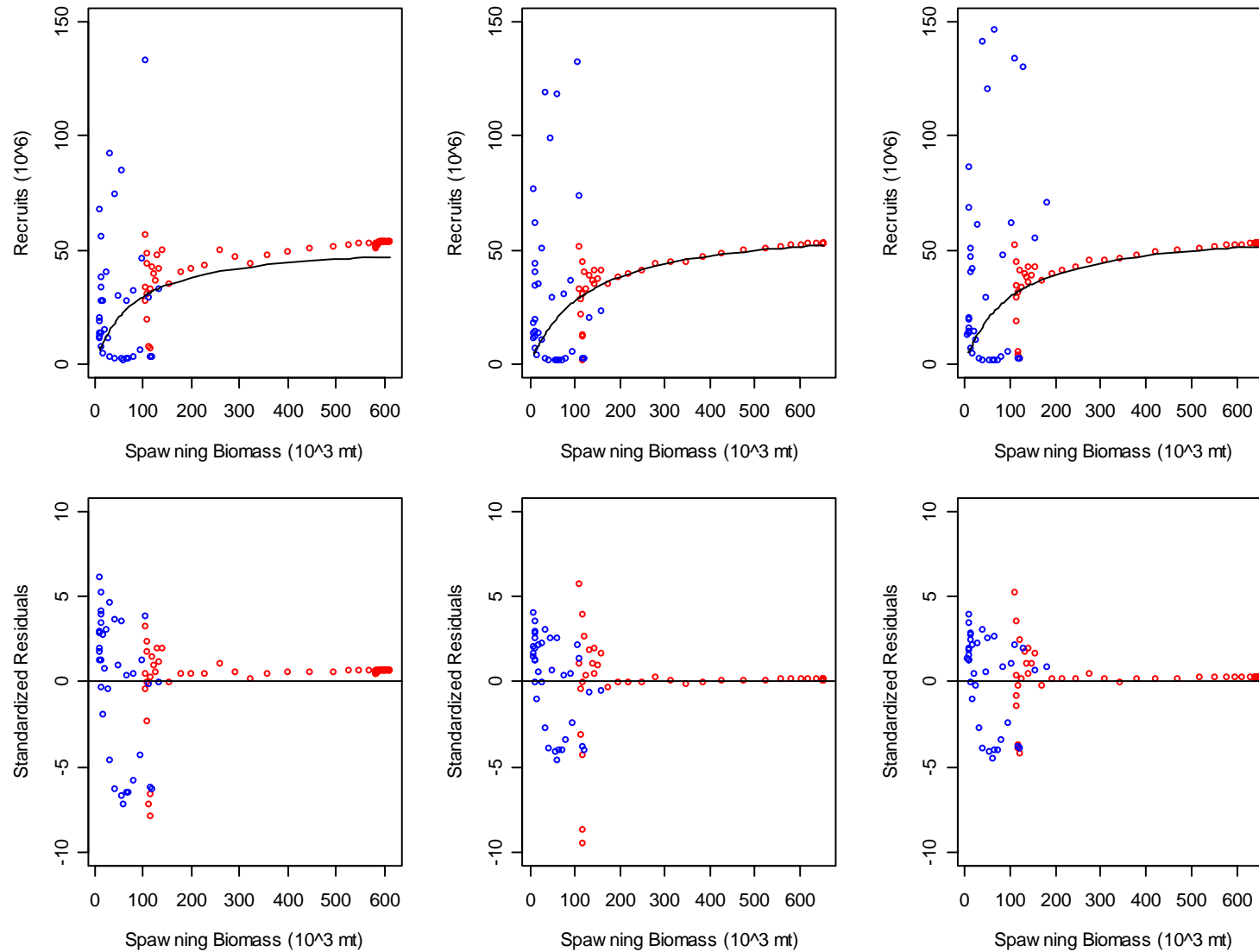


Figure N21. Spawning biomass and recruitment (top) and spawning biomass and standardized recruitment residuals (bottom) from the ASAP alternatives 1 (left), 2 (middle) and 3 (right). The blue and red points are for years where survey age observations are or are not available, respectively.

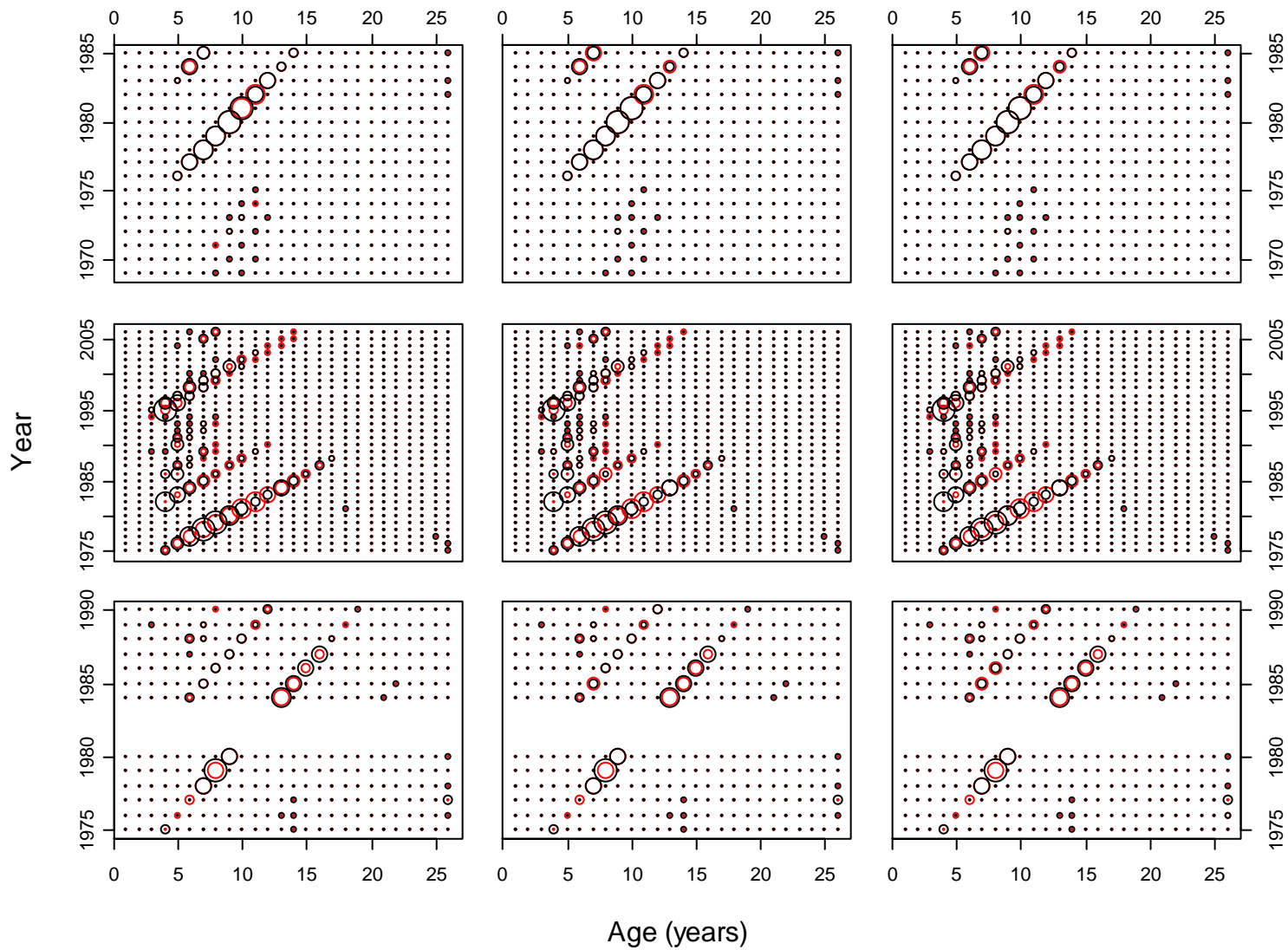


Figure N22. Observed (black) and predicted (red) proportions at age for ASAP alternatives 1 (left), 2 (middle) and 3 (right) in landings (top), fall survey (middle) and spring survey (observed (black)).